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Teemu Karppinen

Two-phased Engineer-to-order Model as Competitive Advantage

Master's Thesis

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Supervisor: Kari Tanskanen, Professor

Instuctor: Antti Taskinen, M.Sc.

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ABSTRACT OF THE MASTER'S THESIS

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The aim of this research is to find out how change orders and their negative effects can be reduced by using a two-phased Engineer-to-Order (ETO) model and other strategies. An in-depth single case study method is used to achieve this objective by relying on both qualitative and quantitative data in order to observe change order dilemma and give valuable suggestions for the case company. Change order dilemma forces manufacturers to accept change orders even though their negative effects are higher than what can be charged from the customer. However, refusing to accept changes can cause other issues, such as negative customer experience and lost sales.

The case company manufactures induction machines and operates in the low-volume ETO sector where profits are low, competition is intense and product lead times are between 12 and 28 weeks. The literature review focuses on change order dilemma by reviewing the constituents of change order occurrence and ways of mitigating change orders and their negative effects. Moreover, the principles of ETO supply chains, common manufacturing issues in the ETO sector and possible strategies for gaining competitive advantage are reviewed.

The research concludes that change order occurrence is high in challenging product groups which include numerous special components. In addition, certain countries, customers and industry specifications increase the likelihood of changes. The negative effects of change orders disturb the order-delivery process and cause additional and hidden costs that are not possible to charge from the customer afterwards. A scenario analysis reveals that the total value of change orders can amount to more than one percent of the annual revenue of the case company.

Findings suggest that both the two-phased ETO model and other strategies, such as increasing transparency between critical stakeholders and enhancing the current change order management practices, are required to overcome change order dilemma and enhance the efficiency of ETO supply chains. The two-phased ETO model helps reduce the number of change orders and mitigate negative effects of change orders. An implementation plan for the two-phased ETO model is developed to increase its usage and clarify criteria and internal instructions to use it for the right projects.

Keywords Change order, engineer-to-order manufacturing, management, supply chain

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Tämän tutkimuksen tavoitteena on löytää tietoa projektimuutosten aiheuttajista ja niiden negatiivisista vaikutuksista sekä selvittää keinoja muutosten ja niiden negatiivisten vaikutusten vähentämiseen kaksivaiheisen tilausmallin ja muutoshallintakeinojen avulla. Näiden tavoitteiden saavuttamiseksi työssä käytetään kvalitatiivisia ja kvantitatiivisia tutkimusmetodeja. Tutkimuksessa selvitetään asiakasyrityksen muutosdilemmaa ja annetaan arvokkaita kehitysehdotuksia. Muutosdilemma voi pakottaa yritystä hyväksymään muutoksen, vaikka sen toteuttamisesta aiheutuisi enemmän kuluja kuin asiakkaalta voitaisiin laskuttaa, mutta muutoksesta kieltäytyminen voisi aiheuttaa vielä isompia negatiivisia vaikutuksia, kuten vähentää asiakastyytyväisyyttä ja myyntiä.

Valittu yritys valmistaa räätälöityjä induktiokoneita ja operoi vähäisen volyymin engineer-to-order-sektorilla (ETO), jossa katteet ovat pieniä, kilpailu on kovaa ja tuotteiden läpimenoaikamallit ovat 12–28 viikkoa. Kirjallisuuskatsaus keskittyy muutosdilemmaan, ja siinä kartoitetaan projektimuutosten syyt, muutosten negatiiviset vaikutukset ja keinot negatiivisten vaikutusten vähentämiseen. Tämän lisäksi ETO-sektorin perusperiaatteet, mahdolliset ongelmat ja keinot saavuttaa kilpailuetua käydään läpi. Skenaarioanalyysi paljastaa, että muutosten kokonaisarvo voi yltää yli yhteen prosenttiin asiakasyrityksen vuotuisesta liikevaihdosta.

Tulosten perusteella muutoksia esiintyy paljon haastavissa tuotteissa, jotka sisältävät useita erikoiskomponentteja. Muita muutosten aiheuttajia ovat tietyt maat, asiakkaat ja teollisuusalat omine vaatimuksineen. Muutokset ja niiden negatiiviset vaikutukset häiritsevät tilaustoimitusketjuja ja aiheuttavat ylimääräisiä kustannuksia ja piilokuluja, joita ei ole mahdollista laskuttaa asiakkailta jälkeenpäin. Löydösten perusteella sekä kaksivaiheista tilausmallia että muita keinoja, kuten esimerkiksi läpinäkyvyyden lisäämistä kriittisissä sidosryhmissä, nykyisen muutoshallintaprosessin parantamista, kokeneiden projektipäälliköiden ja suunnittelijoiden kokemuksen hyödyntämistä ja hyödyllisemmän muutosinformaation keräämistä tarvitaan voittamaan muutosdilemma ja parantamaan ETO-toimitusketjun tehokkuutta. Kaksivaiheinen tilausmalli auttaa vähentämään muutoksia ja niiden negatiivisia vaikutuksia haastavissa projekteissa ennakoivasti. Tätä varten kehitetään implementointisuunnitelma, joka sisältää uusien kriteerien kehittämisen ja prosessimallin levittämisen sidosryhmien tietoon. Siten mallia voidaan käyttää oikein ja sopivissa projekteissa ja lisätä mallin käyttöä välittömästi. Muut keinot parantavat muutoshallintaa, kun muutos on jo tapahtunut, ja ne luovat perustan reagoida muutoksiin tehokkaammin.

Avainsanat Muutos, muutosdilemma, muutoshallinta, engineer-to-order, toimitusketju

Preface

The foundation for the topic was created at the end of the summer 2017 when possible issue areas were identified with thesis advisor Antti Taskinen who is the order-delivery process owner at the case company. The issues discussed were related to change orders and ways to mitigate them by using a two-phased ETO model order that was developed by the case company in the past but had failed in the implementation phase. Taskinen considered this topic worth exploring in this thesis as a part of a larger order-delivery process enhancement project launched by the case company.

The purpose of this study shaped during the winter 2018, and finally the objective was set to studying how change orders and the negative effects of change orders can be mitigated by using the two-phased ETO model and other strategies.

I would like to thank the case company that enabled this challenging opportunity to study this area and Aalto University that gave superior tools and world-class education for the thesis. I would like to thank especially Antti Taskinen and professor Kari Tanskanen at Aalto University who gave brilliant feedback and suggestions related to this thesis. I want to thank the production planning team leader Jaakko Pökkä who helped validate results during the research period and gave beneficial support during the study when we discussed about the topic. Next, I want to thank all employees at the case company who participated in the work observations and interviews, gave valuable insights and helped validate results.

Lastly, I want to thank my family and close friends who supported me during this project and gave me beneficial insights to write this academic paper.

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Teemu Karppinen

Contents

Introduction

The fourth industrial revolution, increased competition and decreased profits are forcing industry manufacturers to be more agile and lean to meet customer demand. Responding to clients' varying requirements has become critical for manufacturing companies and finding efficient ways to respond to them can create new sources of competitive advantage (Fisher, 1997; Wong et al., 2006). However, customers who request change orders after the order fulfilment raise a dilemma for manufacturers because change orders decrease the performance of supply chains, cause non-value-adding activities and unexpected costs that are difficult to charge from the customer (Hanna et al., 2004; Miller and Vollman, 1985; Uskonen and Tenhiälä, 2012).

Different tools and practices are developed to manage customers' special requirements and mitigate the occurrence of change orders (Forza and Salvador, 2002; Uskonen and Tenhiälä, 2012). First, adapting mass customization principles and postponing the order penetration point reduce lead time from order-placing to order-delivery, and thus decreases time for making change orders (Partanen and Haapasalo, 2004). Second, modularity, standardization and product platform tactics are used to overcome change orders (Hoover et al., 2001; Salvador and Forza, 2004). Third, Uskonen and Tenhiälä (2012) identify constituents and accrual mechanism of change orders in make-to-order manufacturing (MTO) for increasing the knowledge about the behaviour of change orders' outgoings.

For each product type, several manufacturer approaches can be used for meeting customers' varying needs and improving supply chain management (SCM). Make-to-stock (MTS) and assemble-to-order (ATO) are forecast-driven supply chains, while MTO and engineer-to-order (ETO) are customer-order-driven supply chains. Each of these approaches has a different customer order decoupling point (CODP) that is also known as the order penetration point (OPP) (Figure 1). For instance, in the ETO approach a product is attached to a customer's order at the beginning of engineering stage but in the MTS approach a product is attached to a customer's order during the assembly stage. The CODP is the final point at which inventory is held, and after the CODP, product specifications are not usually modified. However, more focus has been placed on MTO supply chains while ETO manufacturing approach has been neglected. (Gosling and Naim, 2009.)

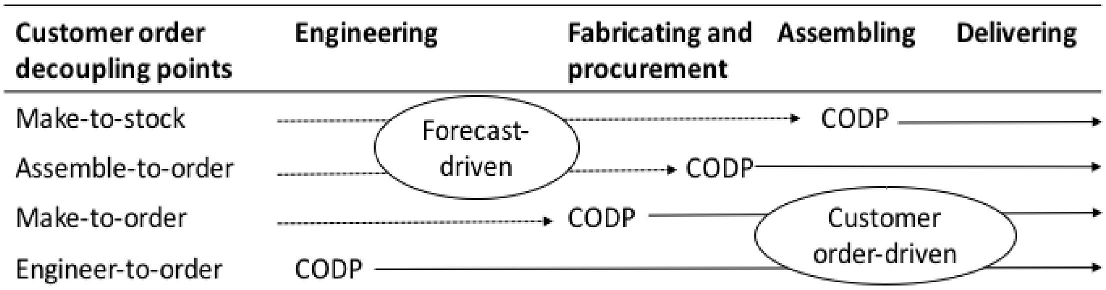

Figure 1. Different manufacturing approaches with customer order decoupling points (Olhager, 2010).

This study aims to increase an understanding of the consequences of change orders and ways to mitigate them in ETO manufacturing by identifying constituents and occurring mechanisms of change orders. For that purpose, a case company was selected from the ETO industry to research these objectives and contribute to the existing literature. The mid-sized case company manufactures highly customized induction motors for large and small domestic and international customers and it is part of a multinational corporation. In addition, product variety is high and volumes are quite low. The industry where the manufacturer operates is a competitive business where profits are low and change orders are common.

This study is structured as follows: First, motivation for this case study is explained. Second, the existing literature on ETO manufacturing principles with issues, main sources of competitive advantages and change orders dilemma are reviewed. These are followed by a research methodology that consists of research approach, research context, data collection, data analysis and validation of results. Finally, the results of the constituents of change order occurrence, the existing and new mitigation strategies and the negative effects of the change orders that could have been mitigated are explained and analysed. This research is concluded with a discussion of the main findings, limitations and future research.

1.1 Motivation

The case company is facing the change order dilemma, and it is identified that this causes negative effects and decreases performance in the ETO supply chain. Thus, costs, risks and lead times are increased in the order-delivery chain, which reduces profits and can decrease customer satisfaction, and hence can lower Net Promoter Score (NPS). Moreover, competition has increased and received orders are far from the best years. Therefore, there is a need to improve supply chain performance to secure profitability and market position. Improving profitability is main goal of the case company.

Finding a new source of competitive advantage can help improve profitability and win more orders in the future if change orders and their negative effects, such as hidden costs inside of the factory, can be mitigated. The two-phased ETO model was identified by the case company in the past but its implementation has not been successful because it is used rarely. Moreover, financial justifications and clear criteria for using the model have not been determined properly. However, this ordering model could offer a competitive advantage to reduce change order dilemma and increase supply chain performance. Even though the two-phased ETO model can offer benefits for the case company and the customers, the model is not utilized well enough for several reasons.

First, the two-phased ETO model is not used enough because customer base, different stakeholders and sales of the company do not know the existence of the model. Second, customers can prefer traditional ETO model because they are used to getting a confirmation for the exact delivery date. The two-phased ETO model can increase the fear of uncertainty because the delivery date can be a critical factor for the customers' projects. Third, the two-phased ETO model is not understood properly in the company because it is used rarely and information about the model is not transferred to new employees well enough. Therefore, the major concerns are more related to the company's processes than system challenges. Since the ETO approach is preferred, many uncertain challenges occur during the manufacturing process and cause bottlenecks and additional cost. Moreover, workload of the business functions is increased, which decreases the agility and increases quality risks, such as on-time-delivery and poor quality because some orders have to be rushed ready before the promised delivery date.

This study is part of the large order-delivery process enhancement project that is launched by the case company. The aim of the study is to overcome the above-mentioned challenges and find justifications for using the two-phased ETO model as a part of the large project. Several professionals from different departments are examining ways to improve the order-delivery process in the large project by focusing on specific part of the process, and hence making sub projects as parts of the large project. This research contributes to some of these sub projects and gives valuable insights about possible future sub projects. For instance, the final detailed implementation of the two-phased ETO model needs to be carried out in the future because different viewpoints for examining sales and customer interface may be required. Cooperation with professionals will give valuable insights into this research and motivation to dive into change order dilemma challenge in the ETO supply chain. As a consequence, this research helps the company in its attempt to mitigate the amount and negative effects of change orders, and give recommendations and information for future business decisions.

1.2 Research Questions

The research focuses on supply chain issues in the low-volume ETO sector that is limited compared to the high-volume sector (Hicks et al., 2000; Gosling and Naim, 2009). Due to limited research in low-volume ETO sector, and complexity and untracked hidden costs of change orders, this research examines the order-delivery process in order to shed light on change order management. This study contributes to low-volume ETO sector by examining the change order dilemma. The main research question is formulated so that it contributes to the existing change order management literature from the viewpoint of ETO manufacturing. The main research question is as follows:

How can change orders and their negative effects be reduced by using the two-phased ETO model and other strategies?

The main research question can be divided into two categories, and further into four sub questions as follows:

A: Change orders at the case company

A1: *What are the constituents of change order occurrence?*

A2: *What are the negative effects of change orders?*

B: Mitigation of change orders

B1: How can the two-phased ETO model be implemented correctly?

B2: What other ways are there to mitigate change orders and their negative effects?

These questions guide this research and make sure the case company's core issue, its impact and the reason for its existence are covered. Several proportions are formulated to test the suggestions in practice. The goal is to find out why change orders occur (research question A1), what hidden costs they cause during the order-delivery process (A2), and how they can be mitigated (B1 & B2). This includes examining ways to implement and use the two-phased ETO model, as well as examining the advantages of the two-phased ETO model. The research is done by studying, for example, induction machines with different degrees of customization, special components and specifications, and identifying opportunities for using the two-phased ETO. The total value of the negative effects of change orders is estimated in order to reveal hidden costs and accelerate the implementation of the two-phased ETO model. Finally, possible competitive advantages are discussed.

Both quantitative and qualitative approaches are needed in this in-depth study to get the overall picture of change orders, explore effects of change orders, identify hidden costs during the ETO process and mitigation strategies. A multisource dataset is used for examining causes and effects of change orders. Simultaneously, the case company's information systems are used to collect new data to support the change order dilemma analysis. Interviews and work observations in the manufacturing and kitting stage are necessary to examine current state of the case company, reveal causes of change orders, hidden non-value-adding activities and hidden costs of the change orders. In addition, interviews in the final acceptance testing stage give information about the negative effects of change orders. Moreover, interviews in the project management and production planning departments give new insights into constituents of change order occurrence and help develop a detailed implementation plan for the two-phased ETO model.

As a result, this research enhances the case company's ability to increase supply chain performance by identifying how change orders and their negative effects can be minimized by using the two-phased ETO model and other strategies. This study highlights the fact that the two-phased ETO model is not the only way to overcome change order dilemma but shows that other strategies to mitigate the negative effects of change orders are required to improve supply chain performance.

2 Literature Review

The structure of this literature review consists of three different chapters. First section focuses on ETO manufacturing and reviews briefly the main principles and issues of ETO manufacturing approach. For instance, determinants of ETO manufacturing environment, such as product characteristics, typical customers and manufacturers are discussed in detail. This section creates a good foundation for the second section that increases knowledge about ways to improve the efficiency of ETO supply chains. The aim is to explore different ETO supply chain strategies which enhance the performance of ETO supply chains and can bring competitive advantage. The last section is focused on change order dilemma from the viewpoint of ETO and MTO manufacturers. Constituents for change order occurrence, negative effects of the change orders and mitigation strategies are discussed in the final section.

2.1 ETO Manufacturing

Typical ETO companies manufacture large entities for the need of gas and oil industry but they can manufacture many other products, such as steam turbine generators, power station boilers and product solutions for mechanical handling and electronic control systems (Hicks et al., 2000; Veldman and Klingenberg, 2009). In addition, different construction projects, such as building and industrial projects are part of the ETO manufacturing, as well as large highway construction projects (Anastasopoulos et al., 2010; Hanna et al., 1999a,b). ETO companies' performance and competitive advantage are dependent on the success of the supply chain management (Gosling et al., 2015). Understanding of the general principles of the ETO manufacturing approach is necessary to realize the mechanism behind the ETO supply chains.

To begin with, ETO manufacturers can use estimates and quotations to win orders and fulfil individual customers' requirements in the customer-order-driven business. As illustrated in the Figure 1, a customer has a major role after accepting the quotation because the customer is attached throughout the entire order-delivery process. Change orders that have effect on design of the product are generally part of the process. Mostly, products are complex and highly customized with depth of product structure, and manufacturing volumes are low (Hicks et al., 2000; Little et al., 2000; Veldman and Klingenberg, 2009). Thus, long lead times and high-value products are common features in the ETO manufacturing (Hicks et al., 2000; Little et al., 2000).

ETO delivery lead time begins from the engineering stage and goes through procurement, production and delivery stages (Figure 2). Lead times can be divided into development, procurement, production and distribution lead times (Tersine and Hummingbird, 1995). Production consists of fabrication and assembly product stages. These product stages can include six main business process components: product configuration, master production scheduling, design planning, project requirements planning, shop floor scheduling and assembly scheduling (Veldman and Klingenberg, 2009).

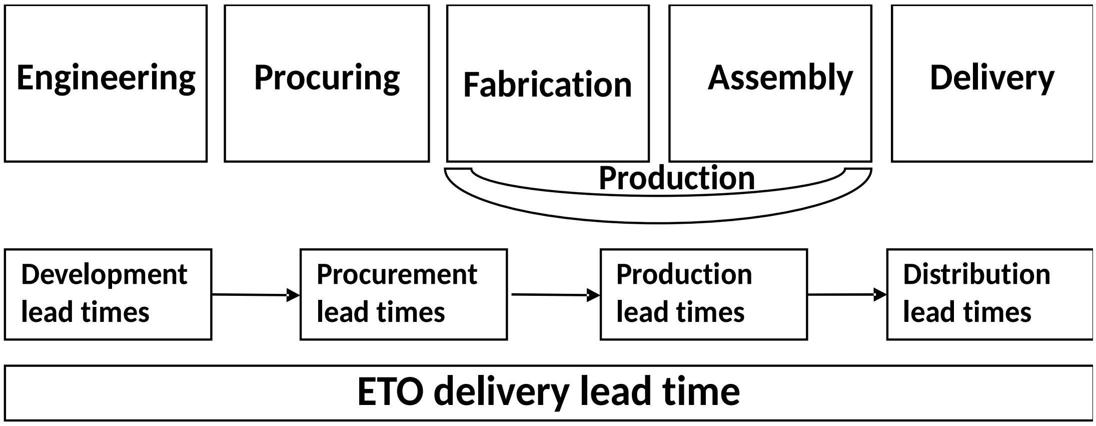

Figure 2. ETO product stages and lead time (Tersine and Hummingbird, 1995).

First, product configuration defines parts that are needed to be designed before the parts can be purchased, manufactured or ordered from inventories. This is a critical activity because even small errors or inaccuracies in the preliminary configuration and specification of a product causes additional rework in engineering and production and can jeopardize on-time delivery. (Little et al., 2000.)

Second, master production scheduling (MPS) assesses critical resources of the manufacturer in order to ensure the potential work load can be managed before the order is accepted. Due to limited resources, overloading of the factory can postpone the required delivery date. Therefore, real-time information about available resources and factory capacity is needed for satisfactory MPS. (Little et al., 2000.)

Third, design planning can be divided into different sub functions, such as electrical, mechanical or hydraulics, and these tasks can require more time than the actual production stage. Because design capacity can be limited, as well as labour efficiencies and skills, the design planning stage should be controlled and measured carefully in order to avoid bottlenecks that are caused by unrealistic workload. (Little et al., 2000.)

Fourth, planning of project requirements is needed for managing manufacturing resources by taking the existing workload and forecasted capacity of all key work units into account and comparing it to available limited resources. For instance, every received order is dealt as a project and this enables a forward scheduling of key manufacturing elements to recognize resource contention and inform completion date of the project for the customer. The excessive overtime work is used to meet promised delivery date, and high percentage of late delivered orders indicate the project requirement planning has failed to manage and identify resources. Projects can be late even if manufacturers need to use excessive overtime work. (Little et al., 2000.)

Fifth, shop floor scheduling supports the final assembly scheduling by planning manufacture of components and coordinating sub-assembly and major-assembly stages. Because of different stages of manufacturing, the shop floor scheduling system needs to be reactive for uncertain events, such as the outcomes of ad hoc meetings and conflicts between different orders. As a result, only a missing minor component or insufficient monitoring of uncertain events can delay the final assembly, which is difficult to fix on time. (Little et al., 2000.)

Sixth, assembly scheduling is a plan of the production operations and parts needed to finish the product for the client. Unstable flow of parts and delays or shortage in component and sub-assembly production can postpone approved delivery date. Moreover, rework at the final assembly stage consumes limited capacity and can jeopardize the approved delivery date. High rework levels can cause procurement issues because fast and expensive deliveries are needed to be used. Therefore, this is a critical activity to complete the product before the due date. (Little et al., 2000.)

ETO business involves several types of complex supplier relationships, and ETO manufacturers can be highly dependent upon outsourcing which can cause challenges or open new opportunities (Hicks et al., 2000). For instance, suppliers' assessments and controlling require resources and cause additional costs. Moreover, low-cost procurement strategy can increase reliability and productivity risks. To end up with, once the customer has received the product, ETO manufacturers can launch important aftermarket service business by providing spare parts and after-sales services in order to maximize profit (Cohen et al., 2006).

Above outlined ETO product stages with numerous business process complements and constituents are sensitive to problems during the order-delivery process. Thus, many different factors can decrease the performance of supply chain and increase lead times (Figure 3). Jahnukainen and Lahti (1999) extend the product stages process chart of Tersine and Hummingbird (1995) and introduce MTO supply chains where most of the problems occur at the interfaces of different departments. Identified problems in MTO supply chains give a foundation for examining issues in ETO supply chains.

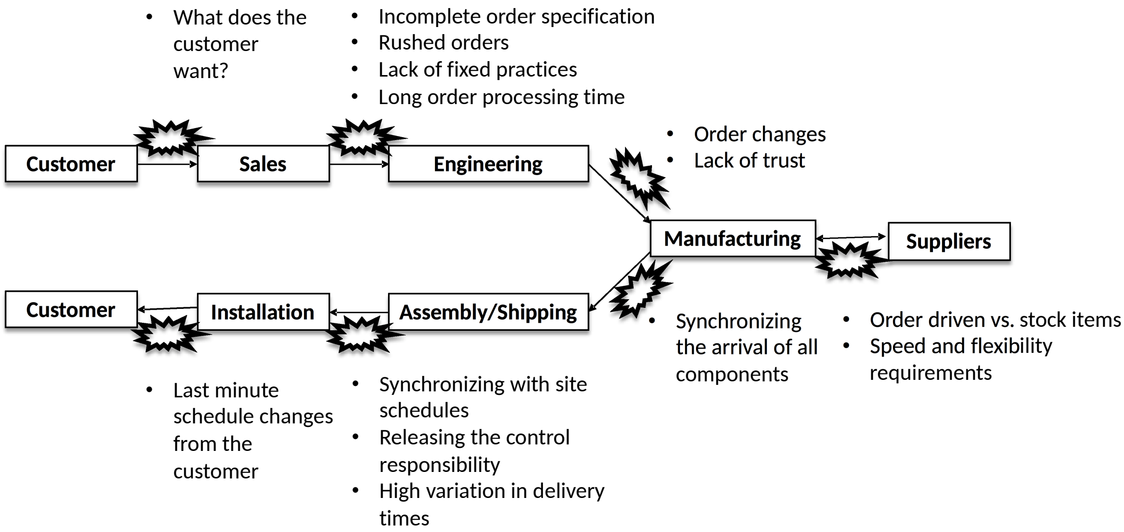

Figure 3. The problems of the delivery process (Jahnukainen and Lahti, 1999).

Low quality of orders is identified to be a major issue that increases order processing time and causes continuous changes (Jahnukainen et al., 1995: Little et al., 2000). For instance, competitive bidding can cause several issues, such as inaccurate product specification and configuration (Little et al., 2000). This can lead to different order changes after an engineering stage which decreases the performance of the ETO supply chains and causes time bottlenecks (Elfving et al., 2005; Gosling et al., 2007). Internal changes are more common than customer changes because tight schedule can force manufacturers to send the order to next stage before a customer has approved necessary product specifications (Jahnukainen et al., 1995). Therefore, missing information and errors, which are usually caused by tendering process and lack of transparency between sales and engineering, are fixed during the order-delivery process if inefficiencies are not identified at the order entry stage (Jahnukainen et al., 1995; Little et al., 2000).

However, these changes can be raised by both suppliers and customers and lead to late engineering changes and modifications which disturb the planned ETO process flow for leading additional actions in order to correct the issues (Veldman and Klingenberg, 2009). Many materials are purchased only for a specific project, and if the customer makes change orders during the process, new materials need to be purchased, and planned manufacturing process needs to be re-planned by different stakeholders. The later the errors are fixed the costlier they are and later occurred change orders have larger impact than early occurred (Gunduz and Hanna, 2005; Jahnukainen et al., 1995).

High rate of products can have defects in the initial configuration, and hence additional resources are needed to correct these errors (Little et al., 2000). This sabotages early and proactive procurements and causes additional costs because it is estimated that about 75‒80 % of avoidable costs can be controlled at the engineering stage (Hicks et al., 2000).

All these above-mentioned problems and the interfaces where the issues can occur are critical factors that affect the performance of ETO supply chain. Thus, supply chain management need to succeed in order to find ways to mitigate all possible issues that can occur (Gosling et al., 2015).

2.2 Improving Efficiency of ETO Supply Chains

The existing literature (Easton and Moodie, 1999; Gosling and Naim, 2009; Li et al., 2006) introduces several ways, such as more efficient SCM, the appropriate manufacturer approach, the right supply chain strategy and product customization, which enhance supply chain performance and bring several benefits, such as agility, improved risk management and profitability. In addition, manufacturing-based competitive priorities and effective sharing of knowledge and information are effective ways to gain competitive advantage (Hicks et al., 2000; Olhager, 2003). Thus, it is essential to review each of these ways to understand competitive forces and different strategies to gain competitive advantage in ETO industry.

One of the main goals of SCM is to reduce costs, risks and lead-times in the order-delivery process, which increase value through the chain (Hicks et al., 2000). This has led to a development of different SCM techniques and tools, which increases profits and enable to achieve goals by understanding SCM as a business strategy (Otto and Kotzab, 2003). Thus, companies, which are treasuring higher levels of SCM practices can affect positively organizational performance (Li et al., 2006).

Researchers have examined the suitability of agile or lean strategy for each manufacturing approaches. Even though the ETO supply chain and agile strategy has received less attention than MTS supply chain and lean strategy, there is some empirical support that lean supply chains may be more appropriate for forecast-driven orders, and agile supply chains may be more suitable for customer-order driven orders (Gosling and Naim, 2009; Olhager, 2010). Gosling and Naim (2009) divided ETO supply chain strategies into seven categories (Shift between supply chain structures, Supply chain integration, Information management, Business systems engineering, Flexibility, Time compression, and New product development process improvement), but the effects of each strategy and their relationships into performance is not clear yet.

Time compression has been identified as an effective strategy to improve ETO supply chain performance. For instance, Towill (2003) concludes that 25 % reduction in costs and total work undertaken is achievable if the project time is reduced by 40 %. Tersine and Hummingbird (1995) research lead-time reduction strategies by highlighting that operating philosophies, such as just-in-time (JIT) and theory of constraint (TOC) are efficient to reduce lead times. They suggest the comprehensive lead-time reduction strategy against all bottlenecks in ETO logistical chain, where all problems related to procurement, production and distribution are located and responded. Therefore, the time management can give the competitive advantage because products can be delivered above minimum customer expectations (Tersine and Hummingbird, 1995).

The degree of customization is next source of competitive advantage (Amaro et al., 1999; Lampel and Mintzberg, 1996). In the ETO supply chains, the degree of customization is usually high because a new design of a product is engineered to order (Little et al., 2000). Therefore, manufacturers can offer high variety of products but their supply chain need to be agile in order succeed in less predictable and high demand volatility business environment (Christopher, 2000).

Manufacturing-based competitive priorities, such as price, flexibility, quality and delivery speed have a positive effect on firm's performance. Especially, on-time deliveries and short lead times are proved to give competitive advantage from the viewpoint of SCM. (Olhager, 2003.) Therefore, short delivery times give a powerful marketing advantage and enable to decrease inventory carrying costs and work in process inventories (Easton and Moodie, 1999).

The effective sharing of knowledge and information is another source of competitive advantage for ETO companies but there is a need for common databases in order to enable transparent and efficient environment for sales, engineering, project management and procurement (Hicks et al., 2000.) As a consequence, engineering and other changes are managed electronically. With the efficient and accurate documentation manufacturers can utilize data to enhance supply chain performance and be more agile. For instance, creating a BOM for each product or establishing a consistent part numbering scheme are general tools to improve operational efficiency and traceability. Finally, for improving the efficiency of the ETO supply chains, manufactures are suggested to decrease design iterations and rework, identify client's requirements straight in the beginning and enhance quality of design and manufacturing (Rahman and Shariff, 2003).

2.3 Change Order Dilemma

The capability of manufacturers is needed to satisfy and respond to wide-ranging and frequently occurring change orders (Uskonen and Tenhiälä, 2012). Change orders can be contractual documents which are requested to accommodate the extra work in the contract (Anastasopoulos et al., 2010). Change orders can be targeted to edit technical specifications of the product or the original delivery date (Vrijhoef and Koskela, 2000). Some manufacturers consider change orders as part of the customer service and natural phenomenon by sympathizing with the reality that the conditions in client's own environments can change during the order-delivery process (Danese et al., 2004). Therefore, products are modified in order to deliver suitable products to meet new requirements (Uskonen and Tenhiälä, 2012). Change orders that occur after order fulfilment cause negative effects, such as decrease the performance of supply chain, cause non-value-adding activities and unexpected costs that are difficult to charge from the customer (Hanna et al., 2004; Miller and Vollman, 1985; Uskonen and Tenhiälä, 2012).

However, refusing to take change orders can be costly because if this disagreement reaches the news, publicly traded manufacturers' market value can plunge by about 13 % and sales can suffer remarkably (Hendricks and Singhal, 2003). To avoid negative publicity, manufacturers face pressure to handle change orders as soon as possible (Uskonen and Tenhiälä, 2012). As a result, change orders cause a dilemma for manufacturers because they are forced to implement change order even though they are not profitable (Uskonen and Tenhiälä, 2012). Therefore, identifying constituents and accrual mechanism of change orders help increase the knowledge about the behaviour of change orders' outgoings (Uskonen and Tenhiälä, 2012).

Hsieh et al. (2004) enlighten the scale of the constituents of change order occurrence and their impacts on the construction industry by developing a framework for the hierarchy of change order constituents (Figure 4). Different categories of change order occurrence and their impacts highlight that occurrence can be challenging to prevent because change orders can even be caused by nature conditions. This also helps understand different causes of change order categories and the negative effects that can be mitigated in the construction industry. All these constituents are not valid in other industries because they may not be affected for instance by natural conditions and underground conditions.

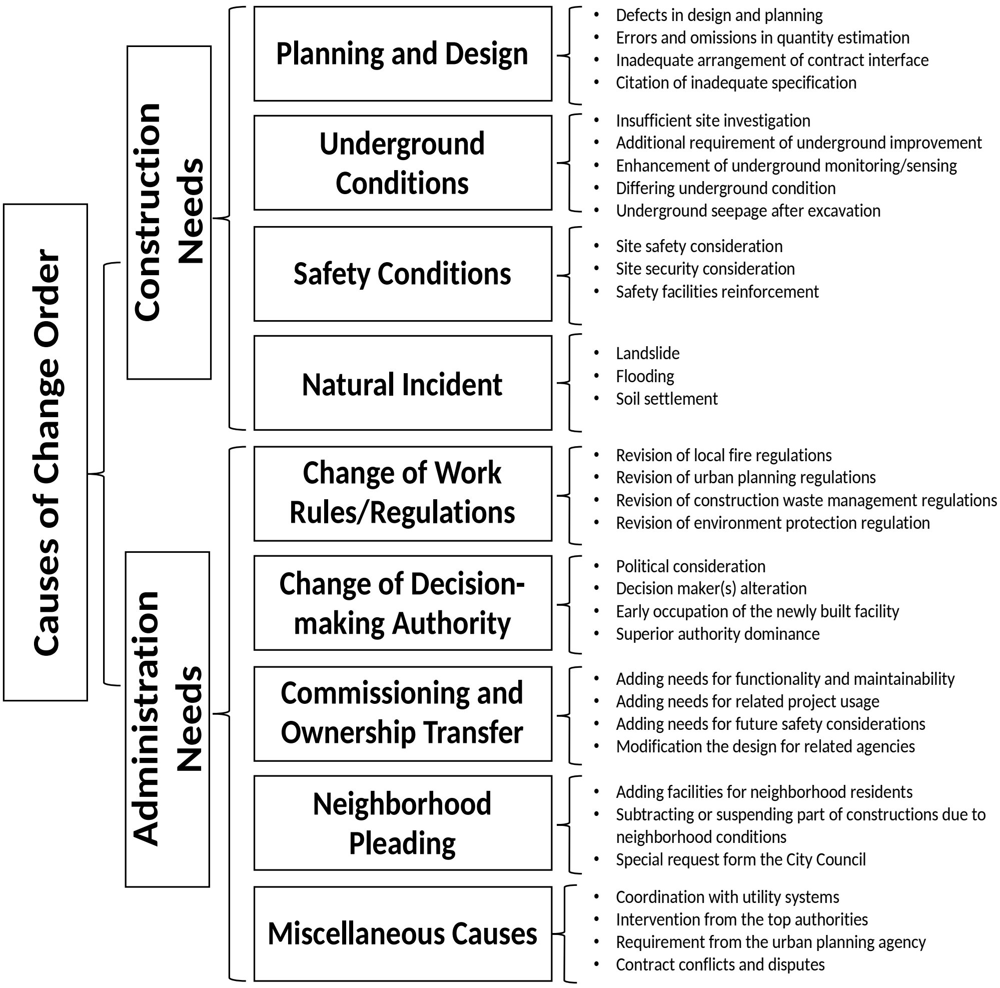

Figure 4. Hierarchy of change orders constituents (Hsieh et al. 2004).

Especially the planning and design category is identified in the literature to be common area that triggers change orders (Alnuaimi et al., 2009; Anastasopoulos et al., 2010; Finke, 1998; Hanna et al., 2004; Hsieh et al. 2004). Therefore, the most general constituents of change orders are produced in the design stage which triggers later design changes, errors and additions (Hanna et al., 2004). Design changes are used for instance in heavy construction projects to correct quantity differences, unforeseen work alterations in the plan, and change specifications of the project in order to meet site conditions and improve operational functionality (Hsieh et al. 2004). In addition, changes need to be executed to correct errors in the project plan and specifications (Finke, 1998). Change orders can also be used to cover fluctuation in projects, amount of materials and unit rate modifications (Alnuaimi et al., 2009). Finally, change orders can also be manufacturer's suggestions which are approved by the customer or its agent (Finke, 1998).

The constituents of change order occurrence are not related only to these internal constituents because there are also external constituents, such as a customer, legislation and even natural conditions which demonstrate the extent of accrual mechanism of change orders. For instance, even site circumstances and weather conditions can be root causes of change orders in the highway construction project (Anastasopoulos et al., 2010). If an ordered product is a minor part of the customer's project, only a small modification can force to redesign the product so that it will fit into the customer's changed project in a site (Hanna et al., 2002). For instance, order plans and schedule change orders are common in manufacturing of capital goods, such as construction materials, because the manufacturer can be affected by turbulent situation of construction sites (O'Brien, 1997).

Other constituents of change orders are related to several intermediate factors, like size of the project, level of bidding competition, contract number and contract duration (Anastasopoulos et al., 2010). Manufacturers are aware that it is challenging to estimate client's actual needs when an order is placed (Huffman and Kahn, 1998). Placing the order is a critical point where miscommunications and mistakes trigger change orders during the order-delivery process (Hegde et al., 2005).

Size of the project has different influences on change order occurrence. For instance, small projects that can be even more beneficial than large projects are usually fast-track-type projects, where a lead-time model is tight and occurred changes lead easily to project extension (Gunduz and Hanna, 2005). Therefore, subsequent modifications for the ongoing sections can be needed afterwards (Hanna and Gunduz, 2004).

On the other hand, lead times are longer in larger projects but risks of facing instant issues are lower because usually there is a dedicated management team which is responsible for productivity tracking. According to Gunduz and Hanna's (2005) research, the mid-sized projects are sensitive to many problems, such as extension of project duration and labour-related problems because they are transition projects between small and large projects. However, the findings of Anastasopoulos et al. (2010) discover that there is a direct relationship between size of the project and frequency of change order occurrence, and they conclude that linear relationships can be found between contract duration and change orders.

Accepting change orders during the order-delivery process can cause major challenges for manufacturers (Partanen and Haapasalo, 2004). The most common negative effects of change orders can be divided into the lead time extensions, disputes, and cost overruns. (Alnuaimi et al., 2009). In addition, there are hidden costs that are not adding value to companies (Miller and Vollman, 1985).

Schedule delays are common because change orders disturb the planned work stage. Moreover, if the implementation process of the change order is hierarchical it can require actions from several stakeholders, such as the contractor and the subcontractor which discuss about the cost of change order, and thus the process can be time-consuming and costly if disagreements of change orders occur (Hsieh et al. 2004). Customer's specification changes, delayed review and approval process as well as customer interference in the design, in the project or in extra design activity are different triggers of schedule delay and disruption in the order-delivery process (Williams et al., 2003). For instance, the project can be put on hold after the change order is requested which usually stops the manufacturing (Hsieh et al., 2004). Therefore, further instructions can be required to continue the manufacturing, or the work force can be moved after change request to the work area where the change order is implemented

(Hsieh et al., 2004). However, Hsieh et al. (2004) identified that in many of the projects, contractor may be forced to continue the manufacturing even though the cost proposal disagreements are present.

Change orders decrease efficiency during the manufacturing process because changes cause bottlenecks if some work areas are congested, increase disruptions in working stages including resource prioritization and interrupt the continuous work routines (Finke, 1998). In addition, Finke (1998) identifies delayed activities and dilution of supervisions as the negative effects of change orders. These delays and work force prioritization have an effect on labour productivity negatively, and it is estimated that the average influence of all change orders can decrease efficiency by 30 % (Thomas and Napolitan, 1995). Therefore, labour productivity decreases more in projects which are impacted by change orders than in projects which are not impacted (Hanna et al., 1999a,b). For instance, reduction in the labour productivity depends especially on phase of the project, timing of the change order and efficiency of the on-site management (Moselhi et al., 2005).

Cost overruns are common in projects that face late changes and in which change order management is inefficient. Change orders that affect manufacturers' profitability are estimated to be up to 40 % of overhead costs by counting change transactions as non-value-adding operations (Miller and Vollman, 1985). For instance, manufacturers are forced to carry out costly additional activities and increase overtime working for executing change orders (Hanna et al., 2004). Moreover, incurred change order costs are complex to be estimated in advance, and thus manufacturers face difficulties to charge customers for these costs (Riley et al., 2005). Change order costs can account from 5 % to 15 % of value of the project depending on the magnitude and the characteristics of the project (Riley et al., 2005). To highlight the impact of change order costs to construction industry in the U.S, it is estimated that from 13 to 26 billion dollars are used to change orders annually (Gunduz and Hanna, 2005).

The most significant variable for the negative effect of the change orders is caused by the timing variable (Serag et al., 2010). If any discrepancies or omissions are identified at the end of project late changes are required even though they increase the project price (Serag et al., 2010). Thus, the project price is highly dependent on the ways the change orders are compensated and how the change orders are implemented (Serag et al., 2010). The project which value is between 10 and 25 million USD the project price can increase from 0.01 % to 15 % if the timing of change orders causes large quantity difference in the project (Hsieh et al. 2004). In addition, changes because of unforeseen conditions, for example unexpected circumstances that affect the project price or completion time of the project, were identified to be one of the most significant factors when the project price increased over 5 % (Hsieh et al. 2004).

The direct negative effects of change orders due to inefficient change order management are additional costs and schedule extensions (Hsieh et al. 2004). Hsieh et al. (2004) introduce several metrics to measure these negative effects because it is typical that change order costs can account from 10 % to 17 % of the total value of the metropolitan public projects (Hsieh et al. 2004). The change order ratio (COR) is used to show the effect of change orders to the ratio of total cost variance of the project and it helps evaluate the performance of the project (Hsieh et al. 2004). It is an index value and calculated by summing total additions and the project value and dividing it by the original tender price (Hsieh et al. 2004). Next, the change order ratio with addition (CORA) is used to display the effect of change orders on the project cost. Sum of additional value of the project is divided by the initial tender price. Other index measure is the schedule extension degree (SED) which is used to measure the magnitude of negative effect of the change order in the project lead time. This is calculated by dividing the project extension by the planned project schedule.

Change orders are difficult to prevent because their occurring is caused by customer behaviour or manufacturer itself (Uskonen and Tenhiälä, 2012). However, it is possible to mitigate the amount of change orders and the negative effects of change orders, and thus many different manufacturing strategies are developed. First, adopting mass customization principles and postponing OPP point to as late as possible, lead times from the order fulfilment to delivery can be shortened which also reduces the time to make changes (Partanen and Haapasalo, 2004). Second, modularity and standardization are efficient solutions to prevent change orders (Salvador and Forza, 2004). Finally, using a platform for information sharing and target development helps cooperate with the customer in order to add value and increase customer satisfaction (Hoover et al., 2001).

The above-identified constituents of change order occurrence and their negative effects can be utilized when mitigation strategies are developed. It is beneficial to identify the changes that are most expensive and then focus on the mitigation strategies to overcome the change order dilemma (Uskonen and Tenhiälä, 2012). Most of these mitigation strategies are focused on design and planning category.

In the beginning, it is vital to identify possible ambiguities at early stage of the project in order to avoid possible disagreements that require expensive changes (Zwick and Miller, 2004). Therefore, the scope of the project should be reviewed early enough to enhance profitability of the project (Zwick and Miller, 2004). As a consequence, negative effects of change orders do not exceed more than 5 % total value of the project, when the project scope is highlighted early enough, experience of the engineering and project reviews are utilized for the pre-contract activities, and the professional construction management firm is selected (Günhan et al., 2007). However, these mitigation strategies which Günhan et al. (2007) tested in the school projects in construction industry can also be suitable in other industries because other researchers, such as Hanna et al. (2004) identified similar strategies to mitigate change orders and their negative effects.

Next, focusing on early stages of the project and implementing beneficial change orders with the right time frame reduce the negative effect of change orders (Kartam, 1996). For instance, additions, design changes and errors can be mitigated theoretically during the design stage (Hanna et al., 2004). Therefore, enough time should be allocated for the design stage, even though it could be beneficial for the owner of the project to start the project as soon as possible (Serag et al., 2010). Because issues in design and planning are common constituents for change orders, change order management as an individual area needs to be focused on (Hsieh et al. 2004).

There are several ways to improve change order management. Change order management team against change order conflicts helps overcome the negative effects of change orders and maintain productivity of the project. For instance, precise documentation of change orders and daily operations during the project enable to manage the occurred changes and help defend against possible claims (Serag et al., 2010). Furthermore, to enhance change order management a web-based system is recommended to be used (Charoenngam et al. 2003). However, overmanning leads to productivity losses because more human resources are needed to manage change orders (Gunduz and Hanna, 2005).

Pricing change orders correctly is important stage in the change order management. It is vital to identify all the possible costs, such as overhead, purchasing services, additional office, engineering activities and profit when preparing a cost estimation for the change order request in order to charge enough from the customer (Hsieh et al. 2004). In addition, project costs can be reduced by focusing on the practices to compensate change orders and identifying how the change orders are expended (Serag et al., 2010).

Project manager's overall experience and familiarity gained in both small and large projects inside of the company help mitigate change orders and reduce losses (Gunduz and Hanna, 2005). For instance, productivity of the project is better if the project manager has enough time to get acquainted with the project. Besides, the experience of contractor or owner from the past ensures less impacted mid-sized projects (Gunduz and Hanna, 2005). Moreover, engineer's support is critical during the project because otherwise projects are impacted by changes, and thus cause losses (Gunduz and Hanna, 2005).

Time-related mitigation strategies should be focused on. For instance, change order processing time should be prompt because the productivity losses are smaller in projects where change order request and approval process can be kept short (Hanna et al., 2004). The transition time from the design stage to the manufacturing stages is a critical constituent which is identified to affect in total profitability of the project (Zwick and Miller, 2004). Moreover, using different freezing points to separate allowable modification periods and setting additional charges for the changes that are the most expensive reduce the negative effects of change orders (Uskonen and Tenhiälä, 2012).

Finally, customer and owner have also key roles in the mitigation of change orders and their negative effects. For instance, the owner should be aware of the consequences of change orders and understand timeframe to make changes. Thus, schedule extensions and costly change orders should be allowed if the scope is changed during the project (Hsieh et al. 2004).

To conclude this literature review chapter, the main findings related to ETO supply chain, most common issues in ETO supply chain, ways to improve ETO supply chain and change order phenomenon are summarized in Table 1. Most of the effort was put on the change order phenomenon because the case company is facing the change order dilemma. Therefore, constituents of change order occurrence, negative effects of change orders and ways to mitigate change orders and their negative effects were reviewed. Change orders can cause significant costs for the manufacturer and decrease efficiency and profitability. Most of change orders can be avoided at the early stages of the project by using enough time for planning and design. Lastly, there are many other ways, such as adopting mass customization principles, increasing modularity and standardization, and enhancing change order management to mitigate change orders and their negative effects.

Table 1. Summary of the literature review.

Focus area	Findings	Authors
ETO supply chain Issues and ways to improve ETO efficiency and gain competitive advantage	ETO performance and competitive advantage are dependent on the success of the SCM.	Gosling et al., 2015
	Most of the problems occur at the interfaces of different departments.	Jahnukainen and Lahti, 1999
	Use efficient SCM, appropriate manufacturer approach, correct supply chain strategy and product customization in order to enhance performance, agility, risk management and profitability.	Easton and Moodie, 1999; Gosling and Naim, 2009; Li et al., 2006
	Decrease design iterations and rework, identify client's requirements quickly and enhance quality of design and manufacturing.	Rahman and Shariff, 2003
	Utilize manufacturing-based competitive priorities, such as price, flexibility, quality and delivery speed, and share information effectively.	Hicks et al., 2000; Olhager, 2003
	Enable high degree of customization.	Amaro et al., 1999; Lampel and Mintzberg, 1996
Constituents of change orders	Planning and design category is a widely identified category.	Alnuaimi et al., 2009; Anastasopoulos et al., 2010; Finke, 1998; Hanna et al., 2004; Hsieh et al., 2004
	External constituents, such as the customer, legislation and even natural conditions.	Anastasopoulos et al., 2010
	Intermediate factors, such as size of the project, level of bidding competition, contract number and contract duration. There is a direct relationship between the size of the project and the frequency of change order occurrence.	Anastasopoulos et al., 2010
Negative effects of the change orders	Most of the negative effects of change orders can be divided into the lead time extensions, disputes and cost overruns.	Alnuaimi et al., 2009
	Labour efficiency can decrease by as much as 30 %.	Thomas and Napolitan, 1995
	Market value can plunge by about 13 % and sales can suffer remarkably.	Hendricks and Singhal, 2003
	Change order costs can account from 5 % to 15 % of the value of the project.	Riley et al., 2005
	Change orders that affect manufacturers' profitability are estimated to be up to 40 % of overhead costs.	Miller and Vollman, 1985
Mitigation of the change orders and their negative effects	Review the scope of the project early enough.	Zwick and Miller, 2004
	Allocate enough time for the design stage.	Serag et al., 2010
	Focus on early stages of the project and implement beneficial change orders with the right time frame.	Kartam, 1996
	Adopt mass customization principles and postpone OPP point to as late as possible.	Partanen and Haapasalo, 2004
	Use different freezing points to separate allowable modification periods.	Uskonen and Tenhiälä, 2012
	Increase modularity and standardization.	Salvador and Forza, 2004
	Use a platform for information sharing and target development.	Hoover et al., 2001
	Enhance change order management process.	Serag et al., 2010
	Identify all costs when preparing a cost estimation for the change order request.	Hsieh et al. 2004
	Leverage the experience of the project managers and the engineers.	Gunduz and Hanna, 2005
	Reduce change order processing time.	Hanna et al., 2004

3 Research Methodology

3.1 Approach

An in-depth single case study method is used for executing this research because it offers several advantages. First, the case study method is a comprehensive research strategy for capturing the holistic and the revealing characteristics of complex real-life happenings (Yin, 2013). Second, due to the exploratory nature of the topic, it enables the recognition of the most relevant factors and their relationship to each other, and thus there is no need for exact generalizations (Handfield and Melnyk, 1998). Third, this single case study research design is helpful to achieve the objectives of this research. Multiple case-study researches were neglected because detailed and vulnerable corporate data related to financial figures is challenging to acquire, and resources are limited to explore the hidden costs of change orders. Fourth, case study enables possibility of triangulating between various sources of data. In this research multiple relevant information sources, such as documentation, interviews, work observations, work experience and process data are used to identify core issues in the current ETO manufacturing caused by change orders. Ensuring high quality of analysis and internal validity, all the relevant evidence is collected for the analysis phase in order to address the main research problem. For instance, additional interviews are used to validate the results of analysis. Finally, inductive approach enables the generation of a new theory from the data and the creation of a foundation for further studies after the main findings of this research are generalized into propositions (Eisenhardt, 1989). Propositions give useful information where to collect relevant evidence but also ensure the research will stay within reasonable limits (Yin, 2013).

The single case design approach is selected to increase the knowledge in the low-volume ETO sector and give valuable insights for the case company and other companies which are responding to customers' change orders at the cost of reduced supply chain performance. Therefore, findings of this research are interesting for the academic colleagues and other professionals in the supply chain management sector.

3.2 Context

The case company is a traditional ETO manufacturer in the induction motor business and has a long history in the industry. The case company is part of a multinational corporation that employs about 135,000 employees in over 100 countries. The case company is a pioneering technology leader that operates in several business areas, such as robotics, power and automation technology with a history of over 130 years. Induction motors are used in different industries, such as food and beverage, marine, mining, oil and gas, power, water and wind, which can include own industry specification and classification.

The case company was selected for the case study because it manufactures about 1,400 highly customized induction motors per year and operates in a low-volume ETO sector where change orders are common. Revenue is approximately 80 million euros per year. High degree of customization and wide variety of product offerings are manufactured to satisfy customers' requirements that can change during the project and can force to make modifications. The current product mix can be divided into PF1, PF2, PF3 and PF4 product categories, and less frequently manufactured PF5 and PF6 product categories. Prices of these motors vary from 30,000 € to a couple of hundreds of thousands of euros. Each product group except PF6 includes several sizes of motors, and the difficulty classes of the motors can be split into A, C or D classes. For instance, motors in difficulty class D are challenging to manufacture because the motors can include many special components, user specifications and complex manufacturing stages, which can cause challenges for engineering, purchasing and manufacturing. PF5 products are challenging to manufacture and are thus class D motors. Lead times for all the difficulty classes range from 12 to 28 weeks. However, MTO manufacturing approach is used for PF6 product group with a lead time of 8 weeks.

Responding to change orders is needed for maintaining customer satisfaction in the highly competitive induction motor business. However, these change orders decrease the performance of the ETO supply chain and cause hidden costs that are not recognised at the case company. Therefore, the change order dilemma is present. The process flow of the order-delivery process is not at an adequate level, and thus the company needs to find an effective way to improve supply chain performance. At the moment the company aims to gain profitable growth because it is one of the corporation's focus areas and seeks ways to gain competitive advantage in the low-volume ETO sector by focusing on different strategic keystones, such as quality, best customer experience, agility and efficiency. Therefore, the case company attempts to find ways to overcome change order dilemma by increasing the usage of the two-phased ETO model and finding other strategies to mitigate the negative effects of change orders.

3.2.1 The order-delivery process at the case company

The order-delivery process is divided into office and manufacturing processes (Figure 5). The manufacturing is customer-driven and every new order is handled as a unique project. There are numerous activities and stakeholders which are part of the order-delivery process.

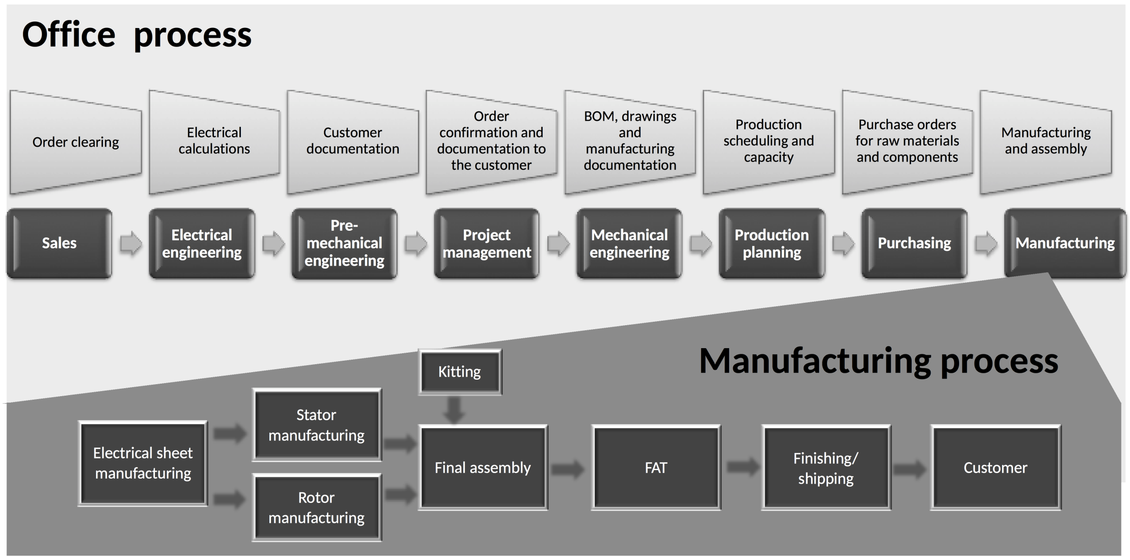

Figure 5. The order-delivery process.

To begin with the sales, the local sales units (LSU) are responsible for the sales process and communication with the customer. LSU checks the quotation before it is sent to the customer. In addition, there are also global and regional sales support units which transfer received information and orders from the LSU to the factory. The communication chain can begin from the end-customer and can go through the subcontractor, the original equipment manufacturer (OEM), the LSU with the sales support unit and finally the case company. Front-end sales organizations are responsible for the quotation process. This includes existing customers who want to replace their old motors with similar ones.

After the customer has made a purchase order (PO), sales is responsible for organizing an order-clearing meeting where a project manager, a production planner, a mechanical and electrical engineer and a purchaser discuss technical details, schedule and potential issues of the project but also check that planned profit margin is acceptable. The order-clearing meeting is a critical stage in the process because all possible risks that may occur during the order-delivery process should be identified there. For instance, with the help of procurement and engineering, the production planning is responsible for securing on-time deliveries by determining the best possible delivery date for the company and the customer. Once the project is approved, it is added to the enterprise resource planning system and order-delivery process can continue to the electrical engineering stage.

The electrical engineering stage is responsible for electrical calculations and modelling that ensures the project can be carried out successfully. For instance, the electrical engineering can suggest that some of the stators need to be manufactured at the factory due to their complexity and ease of monitoring. Also, some components of the project are designed during this stage and can be purchased at a later stage.

After the electrical engineering stage is completed, the mechanical pre-engineering designs the motor based on order information and sends the documents to the customer. Documents include design drawings about mechanical characteristics of the project. This stage is done before the freezing point in order to give customer enough time to check and comment on the documents of the project. The freezing point is the last point when an order can still be modified without disturbing the efficient process flow. If the documents are edited before the freezing point, the original delivery date usually holds. If the customer makes changes after the freezing point, the delivery date is postponed and costs increase for the customer. Due to short lead times and a promised delivery date for the customer, some materials need to be purchased before the freezing point and this can cause additional costs if the customer wants to make changes for the design. Therefore, the freezing point does not always work as it should, and it is not enough to overcome the change order dilemma.

The mechanical engineering begins after the freezing point, and the design for the mechanical work of the project is created. The duration of the stage is usually from 6 to

120 hours and it takes as much time as that the mechanical pre-engineering requires. The mechanical design is done after the customer has approved the documents and the design of the product is final. When the mechanical design is finished, the purchasing department can order rest of the components.

The purchasing department can purchase materials from numerous vendors and focus on low-cost vendors if there is plenty of procurement time. Materials are either bulk materials, which are kept in the inventory, or components purchased specifically for the project. Lead time for the purchases needs to be identified in the order-clearing meeting, and it varies from few weeks up to 16 weeks.

The production planning is divided into production pre-planning, scheduling and production planning stages. First, the production pre-planning adds manufacturing routings and identifies possible special work stages, such as sample coils and bearing inspections, to reserve manufacturing time for every stage after the electrical engineering stage. Second, the scheduling balances workload of the factory, moves determined manufacturing stages to subcontractors and gives a signal for the purchasing to order all the components needed after the mechanical pre-engineering stage. Critical components of long lead time are purchased before the freezing point because lead time models are tight. Third, production planning checks that all possible manufacturing stages can be manufactured without risks after the mechanical engineering stage. In addition, possible change orders and notifications are examined in order to avoid the situation of some issues or changes preventing the manufacturing process. Once change orders and notifications have been dealt with, the production planner can transfer the project to the work queue of the factory.

The project management is responsible for the execution of project and cooperates with the LSU and the customer if needed. By cooperating with several departments, the project management has a major role in accepting and managing change orders. Change order management is a critical area that requires experience and takes a significant amount of time. In addition, the project management can put the project on hold if some information is missing or there are unclear factors. Moreover, the project management approves the project in the order-clearing meeting and sends required documents to the customer.

The manufacturing process includes many different independent and interdependent steps, such as stator and rotor manufacturing, kitting, final assembly and final acceptance testing (FAT). The manufacturing process begins from an electrical sheet manufacturing and continues to stator and rotor manufacturing. Moreover, subcontractors mostly take care of some laborious upstream manufacturing stages, such as the stator manufacturing. Next stage is a kitting stage that is a surplus service for decreasing lead times of the main assembly stage because many laborious and accurate work steps are done in the warehouse of the case company in order to increase performance inside of the factory. The kitting stage prepares connection and main assembly materials for the final assembly stage that can be divided into stator connection, stator inserting, and an actual main assembly stage with various sub-phases.

The stator connection stage prepares the stator for the actual main assembly connections and makes needed cable connections, underpinnings and a rosin stage before the stator is inserted inside of a frame. First two subcategories of the main assembly stage are usually reserved for main terminal box assembly and auxiliary connections that include heating element installation. Next step is a rotor inserting inside of the stator and the frame, after which bearings are installed around a shaft that is part of the rotor. An equipment subcategory includes several metal and electric part installations. Finally, a heat exchanger is installed at top of the motor.

After the main assembly stage, the motor is ready for the final acceptance testing (FAT) stage. However, some testing can be carried out even though all components are not installed. FAT stage ensures that the motor operates properly mechanically. In type test, the motor is tested so that it is same as sold to the customer. For instance, the motor needs to fulfil required performance, heating and efficiency values. Certain industry or customer specifications have an effect on FAT. Moreover, it is common that customer follows this stage to see how motor will perform before it is delivered to the end destination. Thus, there can be customer timetables that affect the FAT date.

Last stages in the manufacturing process are painting, packing and shipping the motor to the customer. After the motor is shipped, service department is responsible for maintaining the motor and making complement installations. For instance, if some less critical components are not arrived before the delivery date, the motor can be shipped without the components because service department can install missing parts in the customer's site later.

3.2.2 Two-phased ETO model

In many cases, the order scope is unclear when an order is received. However, the factory is forced to work in a way that not all engineering is completed before all order details are clarified. This practice decreases lead times and material costs of projects and ensures that the purchased materials are on time and low-cost vendors are used. Therefore, procurement and production can be started without waiting for the document approval. If the order scope changes during the project, it can have a significant impact on costs and delivery time, and these costs are difficult to charge from the customer. This has led to the development of the two-phased ETO model in order to reduce change order costs, increase flexibility for order scope and delivery time changes and harmonize activities with customer project schedule. The two-phased ETO model ensures that the engineering can use enough time for the design of the product and ensure the design meets customer's requirements before any purchased are made.

The manufacturing approaches of two-phased ETO and standard ETO models are similar except for the fact that the two-phase one can be clearly divided into engineering and final order stages (Figure 6). The term pre-CODP is used to illustrate the difference between them.

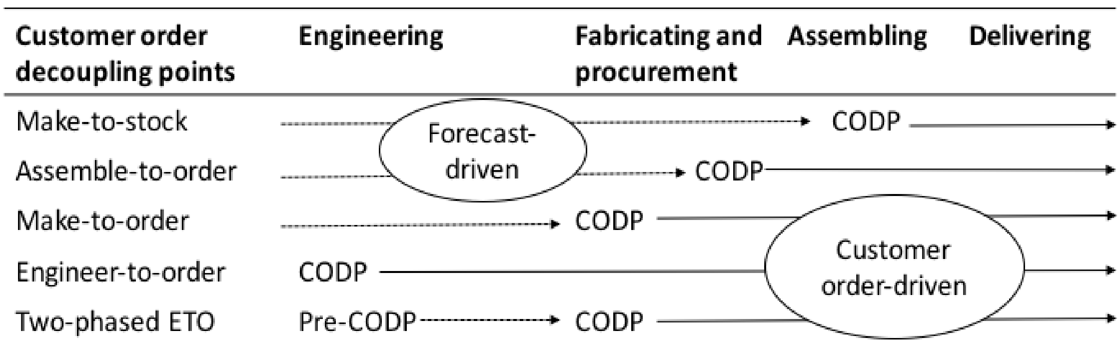

Figure 6. Two-phased ETO model manufacturing approach with different customer-order decoupling points.

In the former stage, the factory is committed to design and release the first set of engineering documents for the customer. For instance, the engineering does not wait or make changes to the first set of documents but completes them based on the information received from the order placement. If open issues exist, they are still left open. The factory needs to wait document approval before procurement or production can be carried out. This stage gives the customers all rights to modify the product until the drawings and documents of the product are as they want them. Thus, the customer can effectively define the freezing point in the process.

The factory cannot provide exact delivery day for the product until the customer has approved the documents and preliminary drawings. Therefore, the delivery date is set to far into the future in order to avoid continuous factory load changes and losses of sales. However, a preliminary delivery date with preconditions can often be given for the customers if required but then there are certain time limits for the customer to approve all the documents.

After the customer has approved the documents, the factory can finally confirm the delivery date and the latter stage can begin. The latter stage is the final order stage where the factory can purchase needed materials and components, manufacture the product and deliver the product for the customer. The product design is frozen after COPD, and thus risks are lower from this point on. At this stage, if the customer still wants to change the product design, the customer is responsible for paying costly modifications and other costs for the company and has to accept that the delivery date can change. In addition, if the document approval process is delayed or the order scope is changed significantly, the factory can change the delivery date and offer a new possible delivery date for the customer.

3.3 Data Collection

Time boundaries determine the beginning and end of the case (Yin, 2013). The time boundaries for this study are from January and August 2018. Multisource data were utilized from the beginning of year 2015 to June 2018. Both quantitative and qualitative evidence are collected for exploring the change order dilemma. Data collection methods relied on documentation and records, interviews, a focus group survey and other observation data collection techniques.

Quantitative data was collected for the research period from the case company's ERP system and project orders. For instance, an exact project schedule, change order information, notifications and financial records were collected. Moreover, factors related to customers and products, such as industry, industry specification, country and product group details were also collected.

After the quantitative data collection, it was possible to form clear and appropriate interview questions that encouraged open-ended responses (Appendices 3, 4, 5 and 7). Semi-structured and informal interviews were carried out to obtain insights about change orders and their negative effects from the interviewees who were managing change orders and experiencing the impact of them. Moreover, it was possible to identify other issues that cause challenges and affect the performance of the order-delivery process.

The list of interviewees can be found in Table 2 in the attachments. A total of 15 interviews were carried out in different departments. The interviewees held different positions in production, sets/sub-assembly, final acceptance testing, production planning and project management departments. All other interviews except email interviews were carried out face-to-face with each individual. Theme interviews were used in production, final acceptance testing, production planning and project management departments. Theme interview materials were used to gather opinions about the collected information in order ensure correct interpretation of the data. Therefore, theme interviews were held with project managers to discuss the data, results and opinions of key stakeholders. Focus group survey technique was used when three experienced sub-assemblers were interviewed. These sub-assemblers had worked together for many years in same tasks. Therefore, it was possible to utilize perspectives and opinions of the sub-assemblers when the information was gathered. The purpose of all these interviews was to achieve a more holistic picture of the change order dilemma.

Finally, several work observations in different departments and meetings were made. First, main assembly observations were made from January 22nd, 2018 to February 9th, 2018 by utilizing the developed measurement list to collect more information about changes, main assembly lead times and issues that disturb the process flow. Second, kitting stage observation materials in 2017 were utilized and compared to focus group survey results. Finally, it was possible to collect qualitative and quantitative evidence related to the change order dilemma by participating regularly in daily activities, such as OTD, change order, and PO meetings at the case company.

Table 2. List of interviewees.

Department	Area of responsibility	Type of the interview	Time
Sets/Sub-assembly	Three Sub-assemblers	Focus group survey	14/02/2018
Production	Production Coordinator	Email interview	20/03/2018
	Production Supervisor	Email interview	21/03/2018
	Bottleneck Team, Supervisor	Email interview	22/03/2018
	Three Senior Assemblers	Theme interview	22/01/-09/02/2018
Final acceptance testing	Production Manager, Test Field	Theme interview	19/01/2018
	Production Supervisor, Test Field	Theme interview	14/06/2018
Production planning	Team Leader, Production Planning	Theme interview	19/07/2018
Project management	Team Leader, Project Execution	Theme interview	27/06/2018
	Project Manager, Central Europe	Theme interview	10/07/2018
	Project Manager, Americas	Theme interview	19/07/2018
	Project Manager, Marine, India, Middle East and Africa	Theme interview	18/07/2018
	Head of Project Management	Theme interview	27/07/2018

3.4 Data Analysis

The main analysis consisted of organizing the collected data in one place and checking it for completeness and accuracy. Next, the data was analysed in Excel. For instance, interview answers from the kitting and main assembly stages were grouped based on issue category. Due to the complexity of the change order dilemma, the data analysis was divided on several phases which are connected to each other in order to ensure the research questions are addressed.

First, the main constituents of change order occurrence are explored by examining documentation and records data and interview materials in order to identify manufacturing stages that are sensitive to change orders and ways to mitigate the negative effects of change orders. Here, the main focus of observations is in the main assembly area because the success of order-delivery process is tested there. In addition, it is also beneficial to explore the kitting stage before the main assembly and the final acceptance testing (FAT) stage after the main assembly in order to identify how challenges in each stage are related to each other and whether the issues are similar or not. As a result, it is also possible to identify more constituents of change order occurrence, their negative effects and other issues that decrease the efficiency of the order-delivery process.

Second, the existing mitigation strategies and new criteria to overcome change order dilemma are explored to identify the negative effects of change orders that could have been reduced by using the two-phased ETO model and other strategies. Moreover, this analysis is focused on finding insights and guidelines about implementation of the two-phased ETO model based on previous analyses and the collected data. The main focus is in finding ways to mitigate change orders and hidden costs without decreasing customer satisfaction and losing new orders. For instance, it is essential to develop new criteria for the two-phased ETO model and ensure it works properly internally. It is encouraged that the model is used if the project fulfils the developed criteria and the delivery date exceeds the lead time model in order to gain more data about the two-phased ETO model for the thesis and in the future. The goal of the implementation plan is to create that helps pushing the model into the sales by highlighting the benefits of the two-phased ETO model.

Lastly, after the key mechanisms behind the change order dilemma are understood and new mitigation strategies are developed, the value of the negative effects of change orders can be estimated by studying projects that could have been manufactured by using the two-phased ETO model. This enables the testing of how the developed criteria could have identified potential two-phased ETO model projects in the past. The purpose is to highlight the financial benefit of two-phased ETO model and other strategies as ways to mitigate change orders and their negative effects. For instance, hidden costs and unnecessary actions that can be caused by change orders are estimated.

3.5 Validation of Results

Validity and reliability of this case study research needs to be considered in order to gain trustworthy results (Yin, 2013). Collected information contributes to the research question in order to ensure results are measuring the selected phenomenon that should be measured (Golafshani, 2003). The main research question and sub-questions were carefully selected and shaped during this study in order to achieve enough valid data about the change order phenomenon at the case company.

Quantitative data is reliable if the results are consistent now and in the future, and substantial representation of the population and the replication of the research by using the similar methodology leads to similar results (Golafshani, 2003). In this research, data was collected from the case company's ERP system and analysed by repeating steps several times in order to avoid mistakes and gain valid results. In addition, numerous measurements were carried out, and the average values from the data were used to gain robust results. The numerical data that was related to the constituents of change order occurrence and the negative effects of change orders was combined with the qualitative data that included discussions with the key personnel, work observations and interviews. The developed criteria for the two-phased ETO model enabled to identify the potential sample size from the population. The sample size consisted of potential two-phased ETO model orders, and the population involved the motor orders in the factory order backlog. The sample size was examined together with the Production Planning Team Leader and the thesis supervisor at the case company because it affected mostly the hidden costs.

Transparency in proper documentation and replication by arranging the data in a structured manner are the key methods to secure reliability (Gibbert and Ruigrok, 2010). All data, work observations with notes and interviews were collected, stored and organized in the research folder into the document and Excel files in order to ensure transparency and replication.

4 Results

4.1 External Constituents of Change Orders

This analysis displays the amount of change orders and examines possible constituents of change order occurrence. For instance, product type, country or customer can cause late change orders and major issues after placing an order. Moreover, the amount of changes after an order is placed and type of changes are analysed.

The number of change order notifications from the beginning of 2015 to March 2018 does not reveal a large trend or difference between different years after June 2015 (Figure 7). Before June 2015, there were more motor orders, which is also reflected to the number of change notifications. However, change order load amount seems to be higher during summer months. The amount of managed change orders is quite stable after June 2015 because the range is from 200 to 350 notifications per month. Therefore, the average values are quite accurate to illustrate yearly change order amount for the period for which the quantitative data was collected.

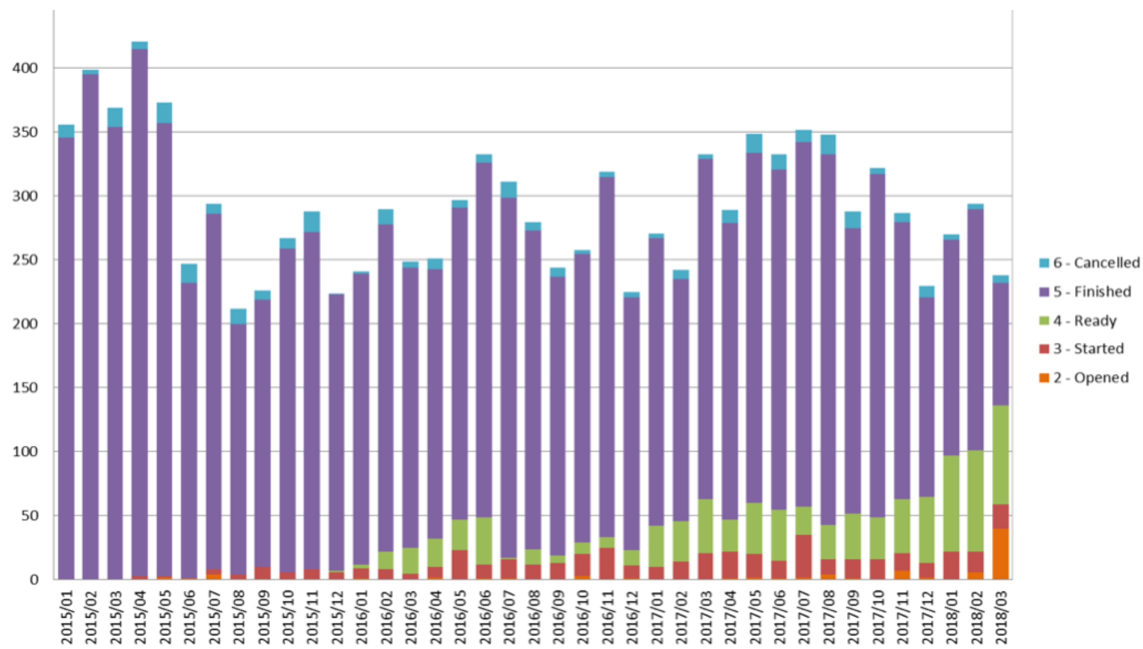

Figure 7. Monthly amount of change order notifications from January 1st, 2015 to March 27th, 2018.

Between January 1st, 2015 and April 27th, 2017, the case company handled 8,287 change orders that impacted on five different categories: structure, documentation, schedule, testing and order (Figure 8). These change categories include both customer and internal change orders. This accounts for over 3,500 change orders per year and if changes are distributed evenly with all delivered motors, there are about 2.42 changes per delivered motor.

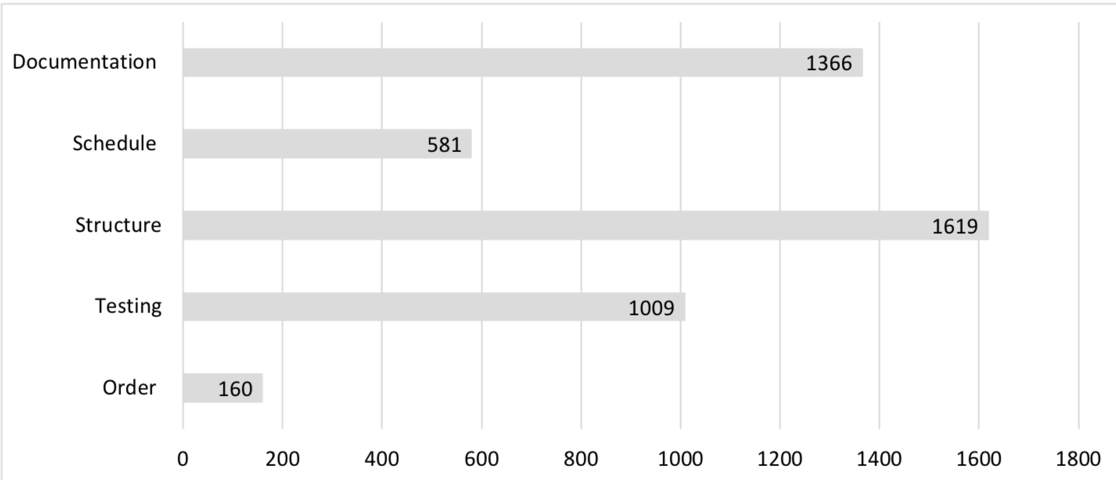

Figure 8. Change orders by documentation, schedule, structure, testing and order (averages per year from January 1st, 2015 to April 27th, 2017).

34 % of change orders were related to structure and 29 % to documentation, and they are the most sensitive areas for changes because these account for over half of the order changes. The largest change category is structure and these changes are related to accessories, casting and heat-exchanger equipment (Figure 9). For instance, changes having an influence on accessories trigger most of the structure changes because the motor can include numerous different accessories. In addition, changes related to the accessories can be easy to implement because these can be assembled at the end of order-delivery process and can be executed before the delivery date. However, other change location does not give beneficial information about the structure change.

"Some components, such as terminal boxes and fans cause changes frequently because the location of the terminal boxes and the rotation of the fan can be designed and understood incorrectly in the sales." – Production Planning Team Leader

However, the rotor and the stator are not so sensitive areas for changes because there are less possible options for changes, the changes must be implemented at an earlier stage and changes can be more expensive and difficult to fulfil.

The second largest change category is documentation, in which the electrical and the mechanical engineering face the most of changes (Figure 10). The mechanical engineer changes are most frequent in this category. Testing and documentation areas are less affected by document changes.

Testing which accounts for 21 % of all changes is the third largest change category, and schedule is the fourth largest with 11 %. For example, changes of test plan and FAT schedule are common change areas. For instance, there can be situations in which the factory is forced to postpone delivery date because of customer changes or internal issues. The order change is the smallest change category.

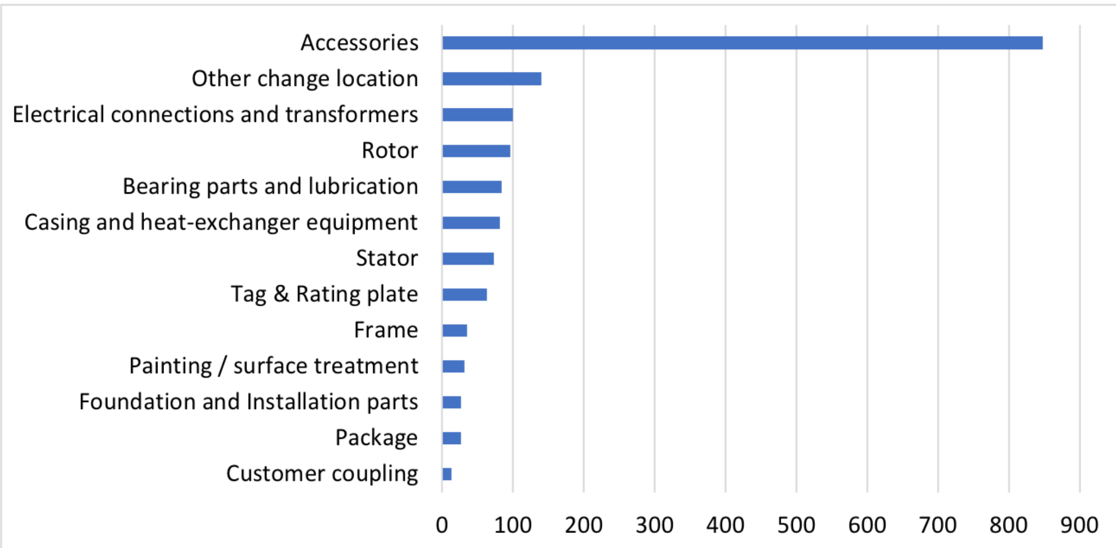

Figure 9. Structure change averages per year from January 1st, 2015 to April 27th, 2017.

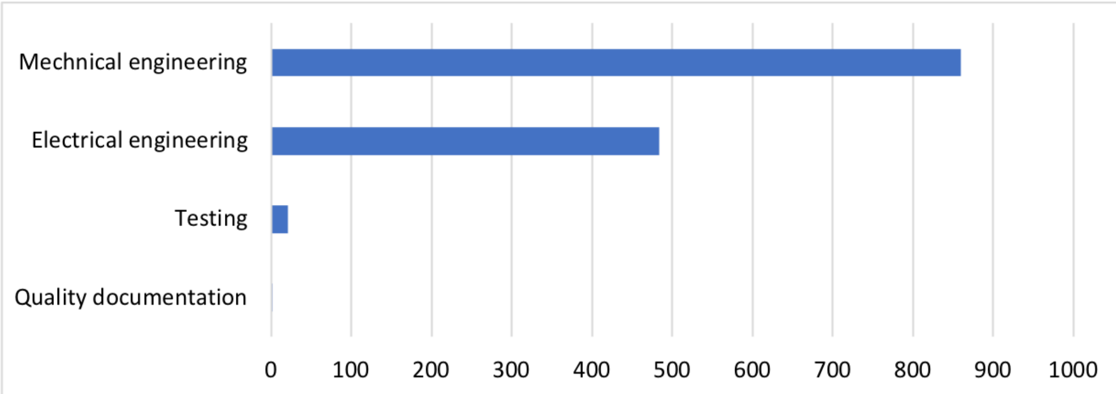

Figure 10. Documentation change averages per year from January 1st, 2015 to April 27th, 2017.

4.1.1 By product family

This analysis helps identify how above-mentioned changes are distributed for the different product groups and which product group difficulties cause more changes than others (Table 3). Moreover, it shows that customer change orders account for almost 3,000 change orders per year and internal changes only a bit over 500 changes per year. Therefore, it displays also whether some product group is more sensitive to customer changes or internal changes.

Product groups with difficulty classes A, C and D have large differences in the number of occurred change orders. PF1 400-630 C and D motor orders generate 59 % of the total change orders per year and are the most sensitive to change orders. It should be noted that PF1 710 D is a new product group and volumes are low – thus number of changes are low. On the other hand, PF2 product group includes many order changes because it is one of the most popular motor types. Proportion of customer and internal change orders between different products does not differ a lot. However, in the PF1 400-500 A product group, the proportion of all internal changes is 10 % which is a high value because the proportion of all customer changes is only 4 %. This can indicate many things, for example lead time being too short, which forces to change Ex Works (EXW) date; or presence of several internal design errors that need to be fixed.

Table 3. All change orders, customer change orders and internal change orders by product group (averages per year from January 1st, 2015 to April 27th, 2017).

Product group	**All change orders**	**Proportion of all change orders**	**Customer change orders**	**Proportion of customer change orders**	**Internal change orders**	**Proportion of internal change orders**
PF1 400-500 C	615	17 %	520	17 %	98	18 %
PF1 560-630 D	534	15 %	440	15 %	81	15 %
PF1 400-500 D	513	15 %	448	15 %	58	11 %
PF1 560-630 C	429	12 %	372	13 %	55	10 %
PF2 C	360	10 %	301	10 %	57	11 %
PF2 D	262	7 %	231	8 %	31	6 %
PF2 A	232	7 %	198	7 %	34	6 %
PF1 400-500 A	177	5 %	125	4 %	52	10 %
PF3/PF4 C	175	5 %	148	5 %	27	5 %
PF3/PF4 A	105	3 %	90	3 %	15	3 %
PF3/PF4 D	65	2 %	64	2 %	1	0 %
PF5	26	1 %	15	0 %	12	2 %
PF1 560-630 A	17	0 %	12	0 %	5	1 %
PF6	9	0 %	7	0 %	1	0 %
PF1 710 D	7	0 %	3	0 %	4	1 %
Total	**3527**	**100 %**	**2972**	**100 %**	**531**	**100 %**

When the ordered motors are compared to occurred change orders per delivered motors, there are only a few projects without change orders in PF1 400-630 C and D product groups (Table 4). On average, every delivered PF1 400-500 C motor causes three changes. Moreover, PF3 D, PF5 and PF1 710 motor types include even more changes per delivered motor. Change amount per delivered PF1 710 motor is high because PF1 710 motors were not delivered in this time frame.

Received sales order data reveals that the volumes per motor type stay quite constant compared to the delivered motors. However, amount of PF1 710 motors is estimated to increase in the future, but the volumes of PF1 710 motors and PF1 560-630 motors cannot be high because the factory capacity and subcontracting set the limits.

Table 4. Change orders, delivered motors, received sales orders, and projects with and without change orders by product group (averages per year from January 1st, 2015 to April 27th, 2017).

Motor type	COs	Deliveries	COs per delivered motor	Received sales orders	Projects with COs	Projects without COs
PF5	26	2	13.0	12	11	0
PF1 560-630 D	534	67	8.0	57	68	0
PF1 710 D	7	0	7.0	3	3	0
PF3 D	65	10	6.5	11	5	4
PF1 560-630 C	429	70	6.1	70	104	0
PF1 400-500 D	513	93	5.5	86	88	5
PF2 D	262	75	3.5	70	50	25
PF1 400-500 C	615	216	2.8	192	168	48
PF3 C	175	82	2.1	101	43	40
PF2 C	360	247	1.5	204	124	124
PF1 560-630 A	17	13	1.3	12	8	5
PF1 400-500 A	177	153	1.2	155	68	85
PF2 A	232	267	0.9	260	111	156
PF3 A	105	132	0.8	143	48	84
PF6	9	31	0.3	27	7	24
Total	**3527**	**1459**	**2.4**	**1404**	**905**	**600**

4.1.2 By geography

This analysis reveals which countries cause most of changes and which change order categories these changes affect the most (Table 5). Especially, Japan generates eight change orders per motor and many changes are related to structure and documentation categories because the degree of customization is high. Next countries Switzerland, France and United Arabic Emirates cause over four change orders per delivered motor. In addition, Germany and Norway have large order quantities. For instance, Germany generates over 800 change orders per year due to high volumes and degree of customization.

Table 5. The effect of country on all change orders (COs), change orders related to documents, order, schedule, structure and testing categories per delivered motor (from January 1st, 2015 to April 27th, 2017).

Sales country	All COs	Structure	Schedule	Testing	Documents	Order	Deliveries	COs per delivered motor
Japan	547	270	44	19	212	2	68	8.0
Switzerland	395	135	38	6	216	0	84	4.7
France	375	178	63	5	126	3	80	4.7
Utd.Arab.Emir	360	137	69	12	137	5	79	4.6
Norway	513	215	69	11	213	5	154	3.3
Germany	803	415	76	9	299	4	242	3.3
USA	426	196	69	6	153	2	153	2.8
Italy	495	261	53	18	162	1	204	2.4
Netherlands	392	173	54	5	160	0	166	2.4
United Kingdom	261	106	58	10	85	2	140	1.9
Spain	286	149	44	5	87	1	160	1.8
Finland	453	188	106	16	143	0	280	1.6

More detailed information was collected to understand which countries impact on each change order category the most (Table 6). Seventeen countries per change order category were ranked based on the proportion of all change orders. Most of the top countries per change order category have made only a few orders, which increases the proportion in all change orders. This information shows for instance that documentation changes in Finland and Switzerland are common, and structure changes in Bulgaria sales office can be high. Therefore, if the order is received for example from these countries, it is possible to focus more on these identified change categories.

Table 6. Schedule, testing, documentation, and structure changes by countries (from January 1st, 2015 to April 27th, 2017).

Country	Schedule	Proportion	Country	Documentation	Proportion
Jordan	1	100 %	Finland, -	115	78 %
Kazakhstan	1	100 %	Argentina	21	57 %
Ireland	6	67 %	New Zealand	10	56 %
Poland	8	53 %	Chile	20	56 %
Lithuania	1	50 %	Switzerland	216	55 %
Ukraine	1	50 %	Qatar	21	54 %
Saudi Arabia	12	41 %	Thailand	60	52 %
South Africa	2	40 %	Belgium	105	50 %
Egypt	21	36 %	Lithuania	1	50 %
Panama	11	34 %	Ukraine	1	50 %
Vietnam	1	33 %	Finland, Process Automation	27	50 %
Hong Kong	7	32 %	Mexico	18	46 %
Pakistan	9	29 %	Hong Kong	10	45 %
Algeria	4	29 %	Taiwan	8	44 %
Hungary	2	29 %	Canada	13	43 %
Turkey	6	29 %	India	50	42 %
Sweden	29	28 %	Australia	38	42 %
Country	**Structure**	**Proportion**	**Country**	**Testing**	**Proportion**
Bulgaria	7	100 %	Slovakia	1	50 %
Ecuador	1	100 %	Egypt	13	22 %
Slovenia	3	75 %	Philippines	4	17 %
Vietnam	2	67 %	Qatar	6	15 %
Finland, Domestic Sales	127	62 %	Malaysia	7	15 %
Panama	18	56 %	Algeria	2	14 %
China	114	55 %	Pakistan	4	13 %
Czech Republic	38	53 %	Greece	6	9 %
Italy	261	53 %	Australia	7	8 %
Turkey	11	52 %	Indonesia	6	6 %
Philippines	12	52 %	Morocco	2	5 %
South Korea	111	52 %	Turkey	1	5 %
Spain	149	52 %	South Korea	10	5 %
Indonesia	53	52 %	Russian Fed.	4	5 %
Germany	415	52 %	Thailand	5	4 %
Pakistan	16	52 %	United Kingdom	10	4 %
Peru	22	50 %	Italy	18	4 %

4.1.3 Other factors

Different sales regions have also an effect on the occurrence of change orders. For instance, Arab world region is sensitive to changes.
"Arab world projects are challenging because the customer may not understand the effect of hold of the project to the schedule. Moreover, FAT practicalities can be unclear, there can be bureaucracy issues, custom restrictions and uncertain legislations." – Project Manager, Marine, India, Middle East and Africa

Another challenging region for the case company is Asia due to cultural differences. In addition, time difference between Finland and Asia can increase communication time and change order process time. There were also other issues, such as lack of skills and uncertain issues which trigger change orders.

"Witnessed FAT can be postponed if the customer does not get visa or flight tickets" – OTD meeting notes

Certain industry specifications cause more change orders than others. For instance, API industry specification triggers change orders if the technical and FAT scope are not clear at the beginning of the project. However, the two-phased ETO model can reduce these change orders.

"Two-phased ETO model ensures the technical and FAT scope are clear and completed correctly, and thus the case company can ensure the documents and quality of the documents are correct. At the moment, there are numerous manual selections that are not so organized in the API specification, and thus there is a possibility for standardization." – Project Manager, Americas

Marine industry products include several classifications, specifications, and usually many special components, which makes the projects complex to implement. Therefore, marine industry causes numerous change orders if all critical factors are not clarified at the beginning of the project. In addition, OTD penalties can be high in this industry.

"The marine motor order process involves the third party who increases challenges because the third party can determine own requirements of which the end customer does not know. The two-phased ETO model decreases these risks because all specifications are not understood correctly at the beginning of the order" – Project Manager, Manager, Marine, India, Middle East and Africa

4.2 Internal Constituents of Change Orders

Internal constituents of change orders can be analysed through the different stages of the order-delivery process. The stages are kitting, main assembly and final-acceptance testing. This chapter reveals negative effects of change orders in the stages which are critical in the order-delivery chain. In addition, possible mitigation strategies to reduce change orders and their negative effects from the viewpoint of kitting employees and work observations are presented briefly in Tables 8 and 9.

4.2.1 Kitting stage

Kitting stage observations and interviews give information about the performance of the order-delivery chain before the main assembly (Tables 7 and 8). The results of the interviews are classified into issue category, description, outcome, impact to main assembly, likelihood and mitigation strategies paragraphs. The impact of kitting issue to main assembly stage is evaluated from zero to three; zero is no impact, one is low impact that can delay main assembly a bit, two is moderate impact that can delay main assembly a lot and three is high impact that can stop the manufacturing or cause quality issues. Likelihood for the kitting issue occurrence is low, medium or high. Low likelihood means that the risk occurs a few times per year, in the medium likelihood it is a few times per week, and in the high likelihood the occurrence is weekly. TPETOM abbreviation is used for the-two-phased ETO ordering model if it can be used to mitigate the negative effects.

The highest likelihood in the kitting stages is related to supplier issue because all materials are not arrived on time. There is no clear reason for the material delays, but change orders, tight lead-time models of the product group and supplier issues, such as unable to manufacture the needed special components on time, can be reasons to material delays. For instance, large and small PF1s are highly sensitive to delays because these motors require usually many special components that can be complex to manufacture, and thus the lead time of these components can be longer than it is estimated in the model. In addition, vendor issues and summer holidays can cause delays, as well as internal issues if the safety stock limits are incorrect compared to the current consumption. As a consequence, the final assembly stage cannot begin on time, which reduces time from later manufacturing stages. However, this is not a problem when the main assembly is also late because the kitting set is not needed before all main assembly materials are arrived.

Table 7. Work observations from the kitting stage in 2017.

Issue category	Description	Outcome	Impact	Likelihood	Mitigation
Supplier	Not all materials arrived on time.	Kitting delay	3	High	Increasing lead time of models with the use of **TPETOM** or demanding faster deliveries.
Outdated documents	Documents are updated after the freezing point. Common for small and large PF1 motors.	Kitting delay	3	Medium	**TPETOM.** Improving transparency.
Workforce	More workload compared to labour capacity.	Excessive workload, kitting delay	1	Medium	Flexible recruiting process for the potential kitting employees.
Internal logistics	Lack of transparency between the factory and the warehouse leads to unnecessary work of finding the materials.	Unnecessary movements to locate materials	2	Medium	Enhancing transparency between the factory and the warehouse.
Supplier/ subcontracting	Supplier/subcontractor issues.	Kitting delay	3	Low	Predictive subcontracting, better auditing, and enhanced transparency.
Internal logistics	Some materials are not arrived from painting subcontractor (NORSOK painting).	Kitting delay	2	Low	Foresight and improving transparency.
Internal logistics	Materials are lost, in the painting or their inventory level is zero.	Kitting delay	2	Low	Improving inventory management and transparency.
Quality	Suppliers' quality does not meet specifications.	Kitting delay	3	Low	Ensuring that suppliers have correct design documents, requiring high quality and using **TPETOM.**
Challenging designs	Difficult designs compared to skills. For instance, PF3 motors with sleeve bearing.	Excessive workload, kitting delay	1	Low	Leveraging experience and increasing transparency.
System	System problems decrease the efficiency of picking the materials.	Increased workload	1	Low	Reducing possible system bottlenecks and educating employees to use the system.

Table 8. Kitting stage interview notes on February 14th, 2018.

Issue category	Description	Outcome	Impact	Likelihood	Mitigation
Supplier	All materials are not available before the planned starting date of the kitting (kitting is on time). This is not a problem when the project is constantly late. Small and large PF1 motors include many specific materials.	Kitting delay	3	High	**TPETOM.** Ensuring that suppliers have correct documents about the design. Supplier auditing. Increasing lead times of the model.
Leftover materials	After change orders, many materials become obsolete.	Additional inventory and motions.	0	High	**TPETOM**. More efficient leftover material management and increasing transparency between the factory and the warehouse.
Outdated documents	Cable glands are different brand than should be.	Confusion and decreased work efficiency	1	High	Information updates. Improved transparency and change order management.
Change order	Wrong material can be used in the main assembly stage if the kitting employee has not noticed to remove the material from the kitting pallet.	Increased risks and confusion in the main assembly	3	Medium	**TPETOM.** Increased transparency between engineering, kitting employees and main assembly.
Skills	Change order information is in English and due to the lack of language skills, the interpretation of the changes is difficult and slow.	Decreased efficiency	1	Medium	Language training for the kitting employees.
Outdated documents	Inconsistency of documents because there can be old and new information.	Confusion and decreased work efficiency	2	Medium	Engineering should focus more on cleaning and updating documents. Improved transparency and change order management.
Skills	It is difficult to get skilled workforce to decrease kitting delays because only a few employees outside of warehouse know how kitting should be done.	Excessive workload and kitting delay	1	Medium	Flexible recruiting process for the potential kitting employees.
Skills	Not enough workforce compared to workload because one employee is responsible for doing kitting of the synchronous machines during the one month cycle.	Excessive workload and kitting delay	1	Low	Flexible recruiting process for the potential kitting employees.
Outdated documents	Uncertainties related to documents.	Additional work to resolve the uncertainty, kitting delay	3	Low	Improved transparency and change order management, more efficient channels to get answers for the notifications.
Lack of transparency about Cos	The change order information does not always reach kitting employees. For instance, if some part of the motor is changed, the main terminal box may have to be furnished again.	Kitting delay and errors	2	Low	**TPETOM.** Increased transparency between engineering and kitting employees.
Outdated documents	Box documents are not always available.	Confusion and decreased work efficiency	1	Low	Information updates and improved transparency.
Supplier	An inappropriate material is delivered, kitting is not finished.	Kitting delay	3	Low	**TPETOM.** Ensuring that suppliers have correct documents about the design.
Challenging designs	Wide variety of different kitting variations.	Excessive workload, kitting delay	1	Low	Leveraging experience and enhancing transparency.

4.2.2 Main assembly stage

PF1 main assembly work observations and interviews helped examine the efficiency of the order-delivery process and identify new constituents of change order occurrence. Moreover, subcontracting issues, engineering mistakes, supplier issues, and logistics challenges were identified to be constituents of change orders. Similar observations were collected from the production managers (Table 9).

Table 9. Interviews of production managers.

Issue category	Description	Impact	Extra work hours	Likelihood
Documentation error	Pre-engineering or mechanical error and poor change order management can cause documentation error.	The work phase or the manufacturing stops. The project can be in hold from 1 hour to several weeks. Moreover, errors decrease efficiency and increase lead times.	1-50	Daily-weekly
Prioritizing	Due to time pressure of closuring EXW deadlines there is need for prioritizing the work schedule of projects.	The current project will be put on hold or someone else will continue it. Moreover, orientation for the high priority project is required after prioritizing but also after the old project is continued.	1-2	Daily
Missing materials in the kitting set	Materials or components are missing from the kitting set for several reasons, such as vendor issues and kitting stage errors.	The work phase stops. Materials need to be searched from the factory and the warehouse.	1-4	Daily-weekly
Missing materials	Materials are not arrived from the warehouse or the suppliers to the factory or materials are lost during the internal logistics.	The work phase or the manufacturing stops. Moreover, the motor can be late in the FAT and cause additional work. Materials need to be searched and several people need to be involved in the searching operation.	1->	Daily-Weekly
Late customer change	Late customer change disrupts the manufacturing process flow. Change order information from the sales office does not reach the factory and the main assembly stage.	The work phase or the manufacturing stops. Manufacturing slots are used to storage motors that are put on hold. The change orders need to be fixed by designing a new component and purchasing the required component.	1-100	Weekly
Subcontracting issue	Many errors, such as low quality, materials are late or wrong material.	Can put the project on hold for a long time if the material needs to be repurchased and procurement time is long. Small quality errors are possible to be fixed in the main assembly.	2->	Monthly

The observations in the PF1 main assembly revealed that lead times of the different manufacturing sub-stage differ a lot between the motor types, and the efficiency of the process flow is disturbed by many factors (Figure 11). It is normal that manufacturing sub-stage lead times differ because some motors include more challenging connections, components and operations than other motors. Moreover, some employees are faster than others because they have more experience from the products and operations.

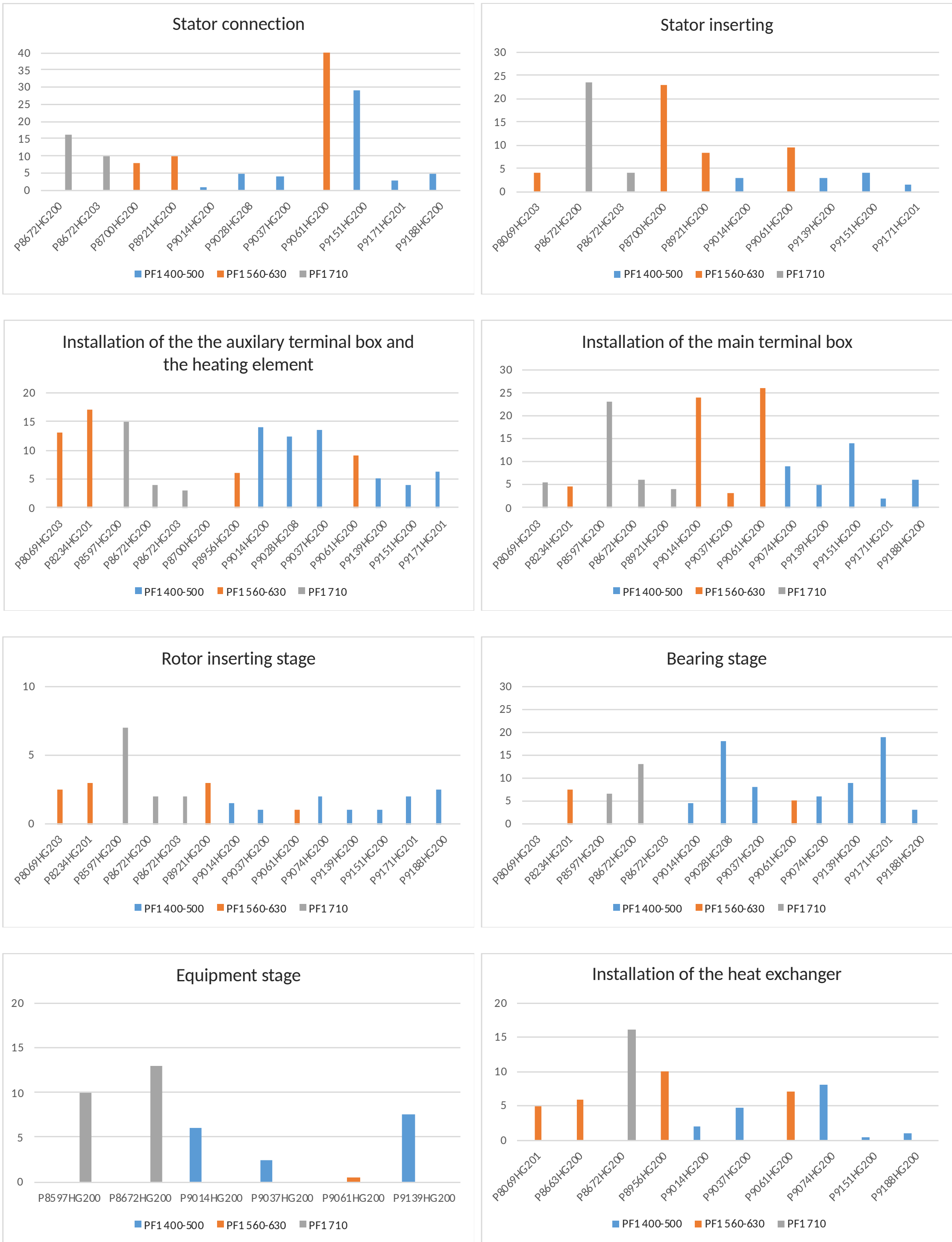

Figure 11. The lead time hours of the different manufacturing sub-stages in the small and large PF1 main assembly by project and product family.

There were several factors that increase manufacturing times, and thus decrease manufacturing efficiency. Every week some PF1 motor is stopped in the main assembly because some components have not arrived on time, there are uncertain issues or some projects are prioritized over the existing projects. First, missing materials and material delays can put the main assembly stage on hold, as well as the kitting stage. In addition, it was highlighted in the kitting stage interview that unfinished kitting sets are sent to the factory in some situations if the delayed materials are ordered straight to the factory. Therefore, there can be missing materials from the kitting set, which can disturb the manufacturing and prevent the main assembly if the missing materials are not arrived to the factory.

Second, many uncertain issues, such as document errors and outdated documents can occur during the main assembly, and thus employees need to make a notification in order to get issue solved before the manufacturing can continue. These identified notifications can be reported as other defects if there are not enough suitable defect categories. The frequency of the documentation errors is high and they disturb the main assembly weekly.

"Even a small error decreases the work efficiency easily for about one hour, modification of the component requires from two to three hours, and the manufacturing of the product is put on hold if engineering support is needed" – Production Managers

Third, disruptions during the main assembly are daily because skilled employees are prioritized to critical projects. Because motors are highly customized and training of new employees requires several months, the importance of skilled workforce cannot be diminished. As a consequence, lack of labour capacity causes sometimes OTD failures.

There are many internal constituents of change order occurrence, system errors, inadequate change order management and human errors. For instance, change order management is not completed successfully because information from the sales office does not always reach the factory and the main assembly stage. These changes are unwanted effects during the process because they disturb the main assembly process and cause non-value adding activities.

"Change orders are challenging because they cause several difficulties for the production management. Technical changes are the most challenging because documentation and mechanical changes make the original documentation outdated, especially in the situation where late technical changes have occurred. Therefore, purchased materials can be wrong, and need to be fixed in the main assembly or

ordered again. Moreover, when the change has been approved, the overall picture of the motor assembly may have not been understood properly, which can cause additional difficulties, such as some materials not fitting into the motor. Also, components can be late because usually there is not much time to order them, and many times the order costs are higher due to fast deliveries. Change orders can cause system problems because if the material is changed, the material can be difficult to order from the warehouse. However, it does not take usually more than two hours to get the material from the warehouse. " – Production Supervisor

Even if the change order can affect FAT plan or schedule, it can cause small issues for the production. For instance, if the FAT schedule is advanced, the production needs to begin earlier and this can cause bottlenecks if the high factory load or delays exist. Therefore, overtime hours have to be used to manage the changes.

To sum up, the overall process flow is not at an adequate level because many different factors disturb the manufacturing stage. For instance, the main assembly cannot begin on time, which postpones next stages. Late changes or poor change order management cause uncertain issues for the production management because wrong materials can be ordered or some materials are not ordered at all. The negative effects of change orders can increase workload from few hours to hundred hours.

4.2.3 Final acceptance testing

This analysis identified the most common issues in the FAT stage and studied how change orders affect the FAT stage. First, vibration issue of the motor is one of the most common problems that disturbs FAT stage weekly. If the vibration issue occurs, additional tests are required to find the reason for the vibration. Next, the motor is transferred to the main assembly to figure out how the issue can be fixed. Therefore, additional work force and testing capacity is used at the expense of other projects. As a consequence, schedule times of some projects can be postponed. In the bad scenario, all active parts, such as rotor and stator, need to be manufactured again to resolve the issue. Normally, a rotor balancing is enough to correct the vibration. PF1 motors are more sensitive to the vibration issues than motors in PF2/PF3/PF4 product groups. In addition, two-pole motors and motors with rotor or fan balancing are the most problematic, as well as PF2 motors which are API specified.

Second, heating problems occur a few times per month, and the accepted limits are exceeded. Thus, the additional heating testing is needed, and the motor is modified in the main assembly again to assemble a larger fan in order to reduce heating. However, it is also possible that new maximum heating temperature can be approved from the customer if the exceeded value is not high or if it is difficult to achieve. In the bad scenario, motors need to be redesigned in order to meet requirements of the customer. PF2/PF3/PF4 product groups are more sensitive to heating issues.

Third, change orders can move FAT schedule but the likelihood is quite small.

"The direct negative effects of change orders are minor in the FAT stage. In most of cases in which change orders occur, motor is sent first to the main assembly where the required modifications are done and after that the motor is tested again. Minor area that can cause challenges is change order management if there is not enough transparency between departments. " – Production Supervisor in the test field

All postponements and issues decrease time from the painting and packing. If the manufacturing stages are postponed it decreases buffer time before the delivery date and causes OTD risks because less time is left for the painting and the packing stages.

Fourth, customer-related factors can disturb the FAT stage because sometimes customer cannot participate in the FAT stage or customer has made a change order which can reschedule the FAT. It was estimated that one rescheduling can take approximately 10 minutes from the testing manager because there are many things, such as resources and delivery date, which need to be taken into account.

Fifth, the negative effects of change orders identified in the earlier stages can cause bottlenecks for the FAT stage. For instance, issues in the kitting and the main assembly stages postpone the FAT and increase rescheduling rate. For instance, over 35 % of induction motors are transferred from the main assembly stage into the FAT after the planned test date that is the first reservation date for the FAT stage. Rescheduling rates differ a lot between the motor types (Figure 12). The rescheduling rate of the large PF1s is highest because the rate is about 54 %. The second highest rescheduling rate is in small PF1 product group that reaches about 36 %. PF2 product group accounts for over

120 re-schedulings because volumes are the highest but the rescheduling rate is the third lowest with 35 %. The lowest rescheduling rate is in the PF3 product group where it is about 30 %.

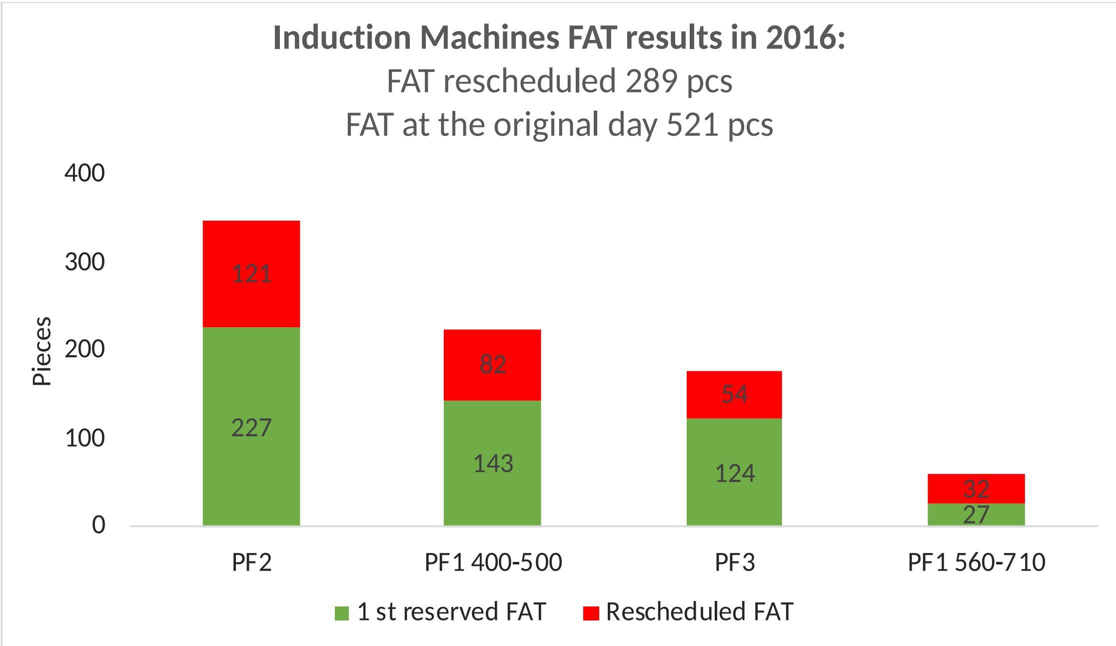

Figure 12. Number of rescheduled final acceptance testing times by product group.

The FAT is a critical stage where motors are tested to ensure the motors fulfil required customer specifications and standards. If the amount of rescheduled motors is almost 300 per year in these product groups, there is a high risk for OTD failures because tests may need to be carried out with strict time pressure and hence there is no time and afford for mistakes. This analysis highlights that PF1 motors that face more changes than PF2 and PF3 motors require higher rescheduling rate than PF2 and PF3 motors.

4.3 Mitigation of Negative Effects of Change Orders

4.3.1 Current practices

The current practices to mitigate change orders can be divided into predictive and reactive factors. Reactive ways to mitigate change orders are overtime work, postponing delivery dates and overmanning, such as daily OTD and change order meetings and weekly regional gate meetings. In addition, the case company has established a change order management team to manage change orders predictively and reactively but this increases also overmanning. Therefore, many employees in different departments are part of the change order management daily. Moreover, freezing point 2 has been used as a checking point before the planned main assembly start date in order to check possible changes. The freezing point 2 process model is used to ensure that there are not coming any changes before the main assembly stage. If the changes are probably occurring after the freezing point 2, the main assembly stage should not be started.

Overtime work is used generally in many departments but especially in the main assembly which is sensitive to issues during the order-delivery process. For instance, if the main assembly stage cannot begin on time, is more likely that overtime hours are needed to finish the motor on time. In addition, engineering department is another work department that uses plenty of time to manage change orders.

Delivery date postponements occur weekly if the project cannot meet delivery date and the customer accepts the changes. Change orders give the project managers an opportunity to postpone delivery date to avoid OTD failures. The delivery date postponements are easy ways to reduce the negative effects of change orders because these postponements secure better OTD value that is important for the company.

Another predictive mitigation strategy is to increase lead times of models by adding additional delivery buffer and material buffers before the manufacturing. For instance, increasing delivery buffer to each product group helps mitigate the negative effects of change orders before the delivery date. Using of additional buffer in each lead time model helps decrease risks, but it increases lead times and reduces possible new sales and gross profit. The longer the lead times are, the more tied-up capital is needed and the more sales are lost if motors wait to the next stage.

4.3.2 Existing criteria for the two-phased ETO model

The existing criteria for the two-phased ETO model are divided into complex project and customer requirements but the existing criteria are not very detailed. The two-phased ETO model is used if projects are complex, critical open item exists or the customer design is not yet in a mature stage. In addition, customer's requirements, such as flexible delivery time, provision for cancellation and certain design freezing point are other reasons to use the model.

However, there are both internal and external factors that have reduced the use of the model. According to production planning team leader and work observations, the model is used rarely because there have not been clear detailed criteria or checklist to use the two-phased ETO model in the order-clearing meetings. In addition, the knowledge about the model has been tenuous because the implementation of the model was not organized in the past. Moreover, the model is difficult to sell for the customer afterwards the sales has offered normal ETO model and confirmed a short delivery date.

Nonetheless, there are several orders that have been carried out by using the two-phased ETO model and that can be utilized in the analysis. The sample of existing two-phased ETO model orders includes 50 motors (Appendix 2). Some old projects did not include any special components (SC) and those are marked as X. Normal lead time (N LT) is days from planned rotor start date to planned packing end date. The actual lead time (LT) from this range is used to compare how many days lead times are above normal (LT above N).

The orders came from the seven different product groups (Figure 13). The products groups are compared later to the potential two-phased ETO model orders to identify the value of the negative effects of change orders that could have been mitigated. The existing orders did not include PF1 400-500 D, PF1 710 and PF5 product groups, and thus comparison was not possible to do between these product groups.

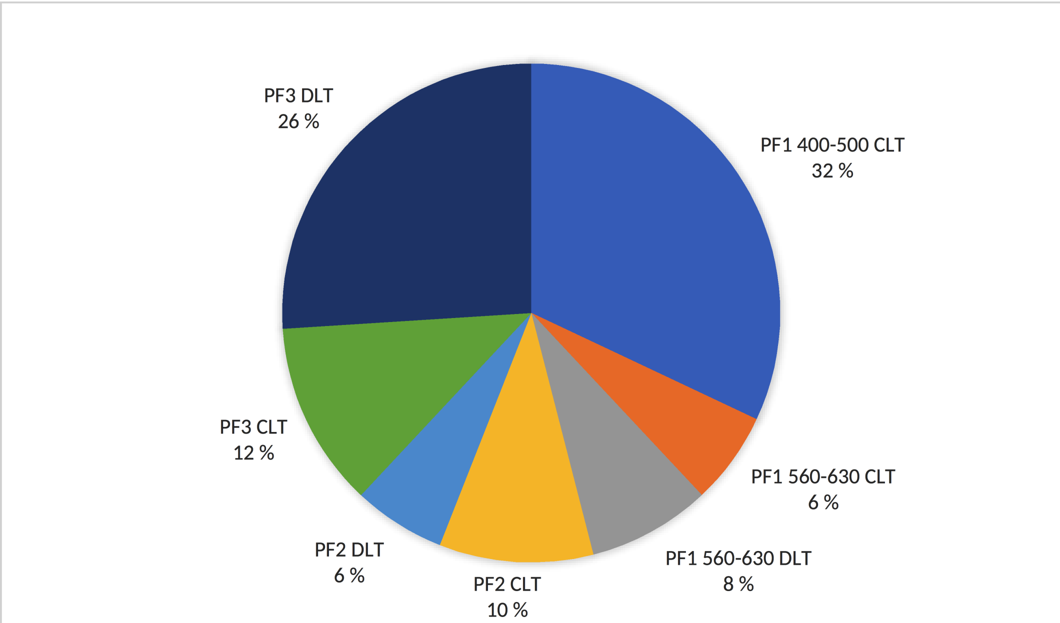

Figure 13. Product group proportions of the existing two-phased ETO model orders (50 motors).

4.3.3 New criteria and model implementation

Identifying and quantifying the negative effects of change orders using the two-phased ETO model (Chapter 4.4) requires a detailed implementation plan that is developed here. The implementation plan is divided into three steps: 1. Find internal criteria for the model, 2. Make sure the model works properly internally and 3. Ensure the sales can sell motors by using the model (Figure 14). In addition, the monitoring and adjustment step begins after the implementation has been completed in order to gain better results in the future. The first two steps began in September 2018 and the third step will begin in November 2018. The purpose of this implementation plan is to enable predictive and reactive possibility to identify the potential two-phased ETO model orders that cause most of the negative effects. Most of the focus should be put on the predictive identification because it is vital that the sales employees can use the model. The two-phased ETO model mitigates change orders and their negative effects as described in Chapter 3.2.2.

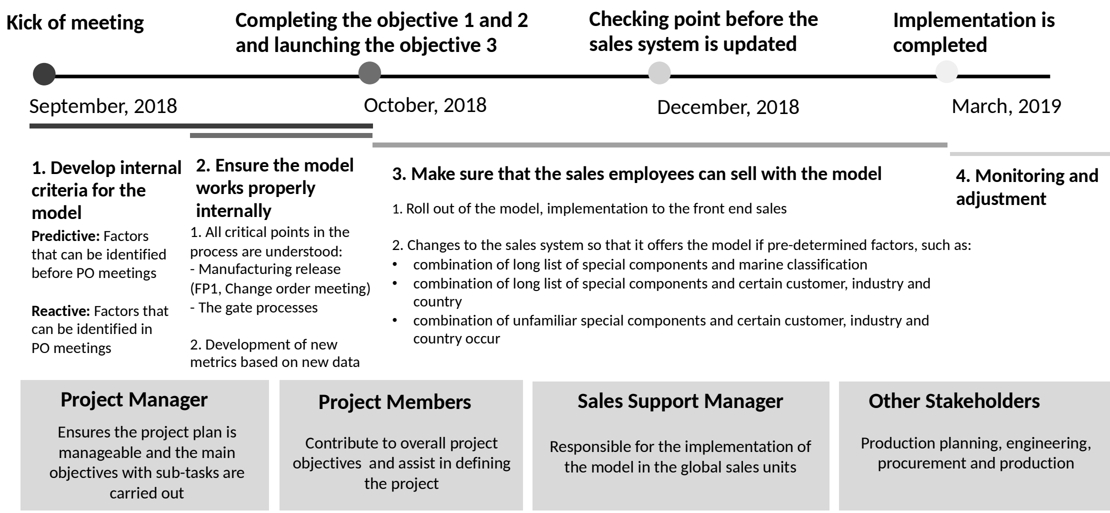

Figure 14. Implementation plan of the two-phased ETO model.

The key stakeholders gathered in the kick-off meeting in September 2018 to ensure that implementation of the two-phased ETO model can begin systematically. Therefore, the implementation team with several roles, such as the project manager and project members, needs to be created. Later, work effort of the sales support manager and other stakeholders is required when the two-phased ETO model is updated into the sales system that sales uses when they make the quotations. Project managers and sales support manager are the key resources in the implementation stage because they know the customer interface and can give beneficial knowledge and insights for the implementation stage. The project manager has the main responsibility for the project by ensuring the project plan is manageable and all the three main objectives with sub-tasks can be carried out according to the implementation plan. The project manager manages the project team by establishing the project schedule, determining detailed schedule for each objective and updating the plan frequently. Furthermore, the experience of engineering, production planning and procurement can be utilized in the implementation stage to monitor and update the criteria.

The first step is to develop and update the internal criteria regularly to identify projects that are sensitive for change orders (Chapters 4.1 and 4.2). This ensure these projects are identified in the order-clearing meeting and enough time can be used for the design and planning stage. The new criteria consist of three main categories: 1) challenging project, 2) customer requirements and 3) other factors which were developed from the existing criteria by making data analyses, work observations and interviews (Figure 15). For that purpose, a detailed criteria checklist for the order-clearing meetings was developed to increase the usage of the model and ensure the model works internally. In addition, it gains beneficial data that can be used when the model is updated into to the sales system.

Five predictive sub-categories in the challenging orders are region, country, industry, specifications/classifications, customer and special components. They all can be identified before the PO meeting, and only one sub-category can make the project challenging. The first reactive main category is the customer requirements which includes document approval requirement, waiting of the production release, provision for cancellation and certain design freezing point requirements. The more there are categories, the more challenges can occur, and the challenges can be identified before PO meetings. The last reactive main category is other factors, which includes unclear scope (critical open items exist) and lack of experience in this project (project manager/ engineer or sales support manager) that can occur during the PO meeting. If some above-mentioned facts of these reactive categories are identified in the PO meeting, it justifies the use of the two-phased ETO model. For instance, if all three main categories are identified, the model has to be used. The project managers have the main responsibility of using the model but also insights gained from the engineering, production planning and procurement departments can affect the selection of the two-phased ETO model.

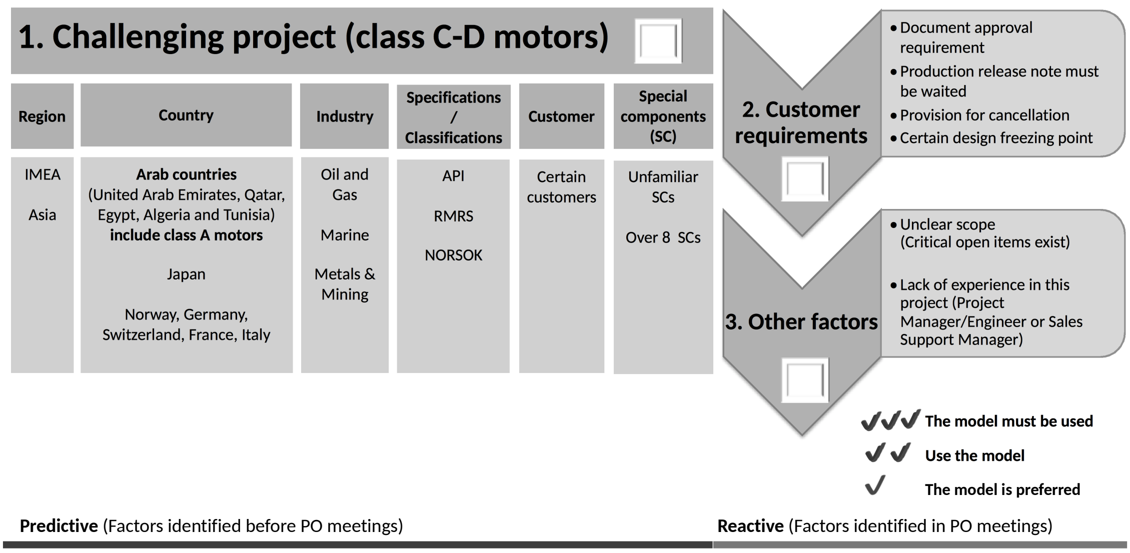

Figure 15. Criteria for the two-phased ETO model.

The second step is to ensure that the model works properly internally. Project managers and engineers should know how to use the model, how does it work and what are the main practicalities related to the model. Therefore, pilot projects were launched already during the summer 2018 to increase knowledge about the model. For instance, two gate process models are developed to ensure the model can be used for the projects where two extra buffers after the pre-engineering and engineering are needed and projects where one buffer after the pre-engineering is used (Figures 16 and 17).

These gate process models are used to display how different stages are related to each other in both cases. Therefore, all critical points, such as freezing point, manufacturing release, scheduling and possible change order management activities, need to be understood properly. Furthermore, bid clarification (BC), order clarification (OC) and order acknowledgment (OA) are other critical points in the gate processes. Due to long lead times, pilot projects ensure that there are more data that can be analysed during the implementation project. As a consequence, new measurements can be developed to monitor and polish the model even further. For instance, information that is available from the OTD meetings and work observations in daily projects could be utilized to the update the checklist. Objectives 1 and 2 are possible to be completed at the end of October 2018 because no additional research is required as the checklist to use the two-phased ETO model orders is already developed and pilot projects are launched frequently if criteria for the model fulfil.

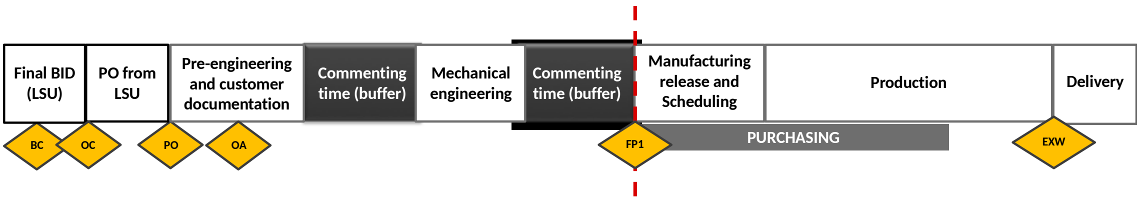

Figure 16. Gate process of the two-phased ETO model with two buffers.

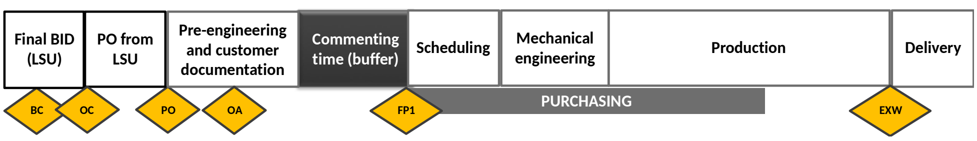

Figure 17. Gate process of the two-phased ETO model without second buffer.

The third step is to make sure that the sales employees can use the model. This requires more effort than the first two objectives because the sales system needs to be updated and the front-end sales needs to informed about the model. The main goal is to update the sales system so that it recommends the model for the front-end sales if the model could be offered. The purpose is to push the model to the use of the front-end sales by updating the sales system. For instance, the sales system offers the model if some of the pre-determined criteria occurs when the sales employee is preparing the quotation. These pre-determined criteria can be based on the checklist and certain combinations in the checklist. For instance, one combination could be a long list of special components and a marine classification and another longer combination could be unfamiliar special components, certain customer, industry and country. However, only one factor, such as a certain customer can force to use the model if it has caused major negative effects of change orders in the past.

The last step is to monitor and adjust the usage of the two-phased ETO model. The two-phased ETO model does not work if the rules are not clear for the customers. If changes are made before the manufacturing release they are preferred but making late changes cause penalties because the process flow efficiency decreases. The company does not have to be too flexible for the customer; otherwise the customer has a stronger control of the order-delivery process and the customer can cause hidden costs. Increasing transparency between customers can help mitigate risks and negative attitudes. In addition, the company can learn from the customer if the customer is more involved in the process. Moreover, every employee who is related to the order-delivery process can affect the outcome of each project. Many new metrics can be used to measure and evaluate how the two-phased ETO model projects are performed. For instance, the amount of change orders, lead times from the rotor start date to packing end date, gross profits, overtime hours and NPS values can be monitored and examined. In addition, it is possible to observe and identify whether the company is able to increase sales if the production lead times are reduced. As a consequence, new measurements help develop the model even further and justify the use of the model.

4.4 Negative Effects of Change Orders

Even though change orders can be profitable business, these changes cause many hidden costs areas, such as overtime costs and loss of sales and investment opportunity. The first part of the analysis examined overtime hours and estimated overtime-cost value. Next parts of this chapter focus on the negative effects, such as loss of investment opportunity based on tied-up capital, and loss of sales and loss of gross profit which are possible to be reduced with the new mitigation strategies. For this purpose, the new criteria for the two-phased ETO model were used to identify the potential orders. This gave a good opportunity to test how the new criteria could have been worked in the past and highlight the amount and distribution of potential orders by returning back to the PO situation. This financial analysis compared the existing two-phased ETO model orders to the similar potential ETO model orders to find the negative effects of change orders that could have been avoided by using the two-phased ETO model.

Finally, the above-mentioned negative effects were summarized to show the total sum that could have been mitigated by using the model and other strategies. Therefore, the cumulative saving potential for each cost saving area is presented at the end of each analysis chapter. For the loss of sales and investment opportunity analyses, it was necessary to collect a sample that could have been manufactured by using the two-phased ETO model order.

4.4.1 Overtime costs

This analysis observed overtime costs in 2017 in different work centres and estimated the value of overtime costs that can be reduced by using the two-phased ETO model and other strategies. Six different work centres needed 10,403 overtime hours in total to complete necessary tasks in 2017 (Figure 18). Almost 88 % of all overtime hours were made during the weekend. Therefore, the average cost per overtime hour is high because weekend days are generally more expensive than weekdays. This accounts for approximately 554,000 € per year and thus the average overtime cost per month is approximately 46,000 €.

Most of the overtime hours are required in the work centres, such as engineering and main assembly that execute most of the change orders. The engineering manages over half of the order changes because structure accounts for 34 % and documentation 29 % of all change order types (Figure 8). All engineers can manage these changes. If these change management hours are transferred into the work hours, from three to six full time engineers are required to manage the changes. If there is high workload, overtime hours can be required to manage also normal orders.

The main assembly implements most of the changes that the engineering department has done. For instance, most of overtime hours were used in PF2/PF3/PF4 main assembly stages and PF1 main assembly is the fourth largest overtime cost center. Work observations and interviews in the PF1 main assembly justify the amount of overtime hours because even a small change order, engineering error or procurement issue can postpone the main assembly. Thus, overtime working mainly on weekend can be the only option to manage these postponements to meet the promised delivery date and avoid OTD penalties.

Painting and packing stage achieves the second highest overtime hours. It is the last stage before the shipment which indicates that the issues in the earlier stages are accumulated here. Therefore, weekend days are needed to finish the painting and packing of the motor on the required week and securing weekly OTD value.

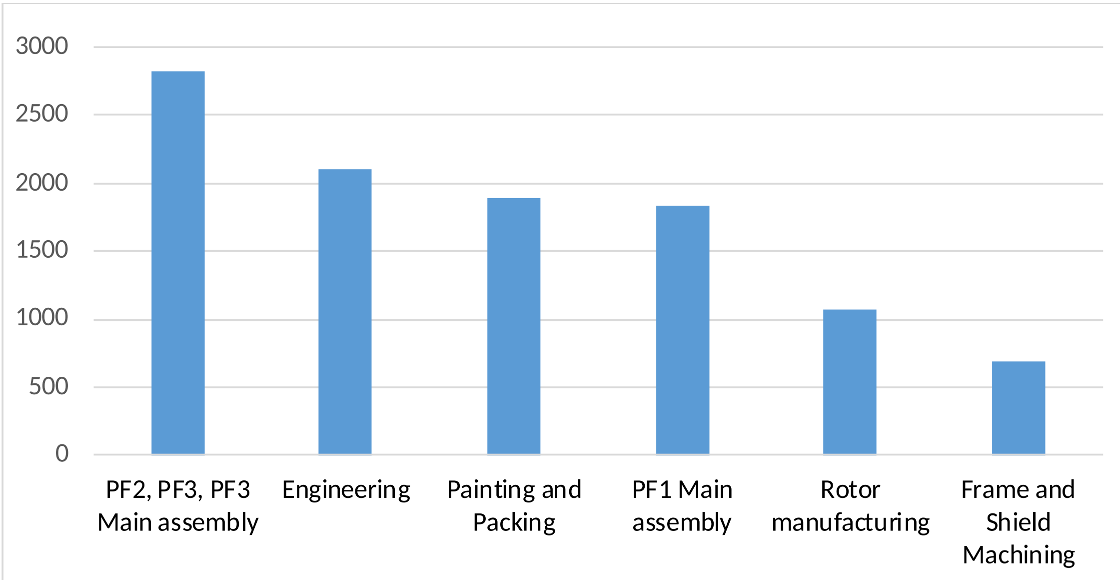

Figure 18. Overtime hours by work centre in 2017.

This large amount of overtime hours used in 2017 offered a good opportunity to highlight the value of mitigatable overtime costs. Three different scenarios were made from January 2018 to December 2020 in order to estimate a reliable range of the cumulative overtime cost saving potential that the two-phased ETO model could offer (Figure 19). It was assumed that about half of the total overtime costs could be theoretically mitigated by using the two-phased ETO model and another half by using other strategies because there are numerous internal factors, such as unstable work load in the engineering department, lack of work force and skills, and quality issues, and thus they are not possible to be mitigated by using the two-phased ETO model.

First, unstable work load in the engineering department requires overtime hours especially during the summer when there are less engineers. Summer capacity of the manufacturing is lower than rest of the year but the engineering department can have almost the same workload during the summer holiday season. However, documents need to be designed for motors that are delivered next autumn when factory capacity is at the normal level. As a consequence, engineers have normal workload during the summer and less work in the spring.

Second, due to complexity and wide variety of motors, challenging change orders and quality issues, experience and professional skills are needed daily. If a highly talented professional is absence or uses worktime for changes, it can require more effort from another professional in the main assembly. Finally, unstable workload can cause bottlenecks in the main assembly if there is not enough capacity to manage the existing load.

Procurement issues, such as delays in component deliveries or sub-contracting are external factors that are difficult to be prevented by using the two-phased ETO model. For example, vendors' and sub-contractors' summer holidays and other customers' orders can disturb the order-delivery process. Therefore, there are several stakeholders, such as tier 1 and tier 2 companies which can cause delays in the supply chain and trigger overtime hours to deliver motor on time.

Due to these above-mentioned factors that affect the overtime costs, 276,000 € per year and 23,000 € per month were used to estimate the range for the cumulative overtime costs savings in each scenario. Saving potential is approximately 18,500 € in the good scenario, 11,500 € in the moderate scenario and 4,600 € per month in the worst scenario. As a result, the range of cumulative savings from to January 2018 to December 2020 is between 86,400 and 666,000 €.

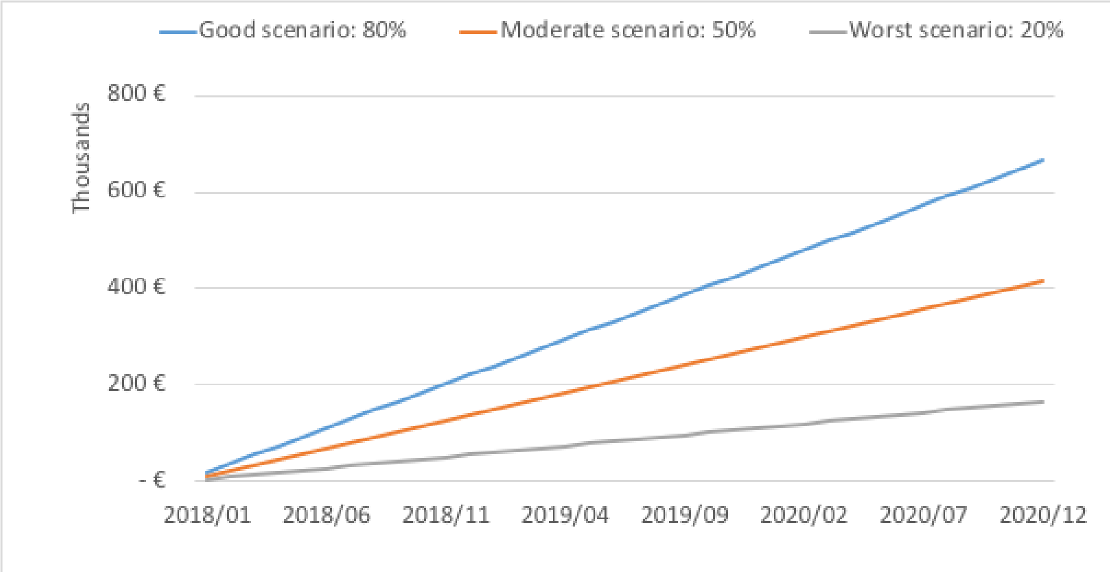

Figure 19. The cumulative overtime cost saving potential that the-two-phased ETO model could offer from January 2018 to December 2020.

4.4.2 Loss of investment opportunity

There were several steps to calculate the loss of investment opportunity because of increased tied-up capital time period. First, motors which planned delivery date was from November 6th, 2017 to May 11th, 2018 were part of the sample. This accounted for 634 motors but after the developed criteria were utilized, there were 92 motors left out of 634 (Appendix 1). The more there were factors that supported the usage of the two-phased ETO model, the more there were reasons to select the project for the analysis. From the project view, 52 projects out of 341 were suitable for the two-phased ETO model. 31 motors out of 92 caused OTD failure even though the delivery date was postponed in some of the projects during the order-delivery process and thus the new criteria could have been also mitigated the OTD failures.

The distribution of the potential orders displays how these motors have been received into the factory order backlog (Figure 20). These potential orders have been received between August 2016 to December 2017 and it shows that some orders can be received over one year before the delivery date. If the sample had included all potential orders from longer period there would have been more potential orders in the Figure 20. As a consequence, the factory can receive weekly approximately two potential motors which can be manufactured by using the model.

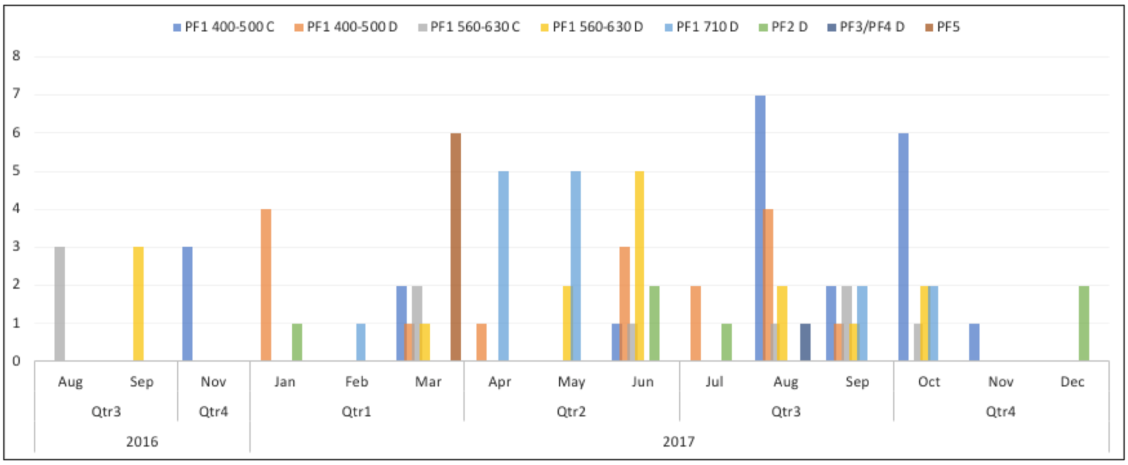

Figure 20. Received potential two-phased ETO model orders that have EXW date from November 6th, 2017 to May 11th, 2018 (92 two motors).

The potential two-phased ETO model orders are mostly challenging PF1 motors that include more components than PF2/PF3/PF4 and PF5 motors. About 85 % of potential motors were PF1 motors and the rest of motors were PF2 D (7 %), PF3/PF4 D (1 %) and PF5 (7 %) motors (Figure 21). The largest product group is small PF1 400-500 C class with the proportion of 24 %. Three next largest product groups are PF1 400-500 D (17 %), PF1 560-630 D (17 %) and PF1 710 D (16%). Taking into account that PF1 560-630 cannot be manufactured more than six per week and PF1 710 one per week, the proportions of the PF1 560-630 D, PF1 710 D and PF1 560-630 C product groups are high.

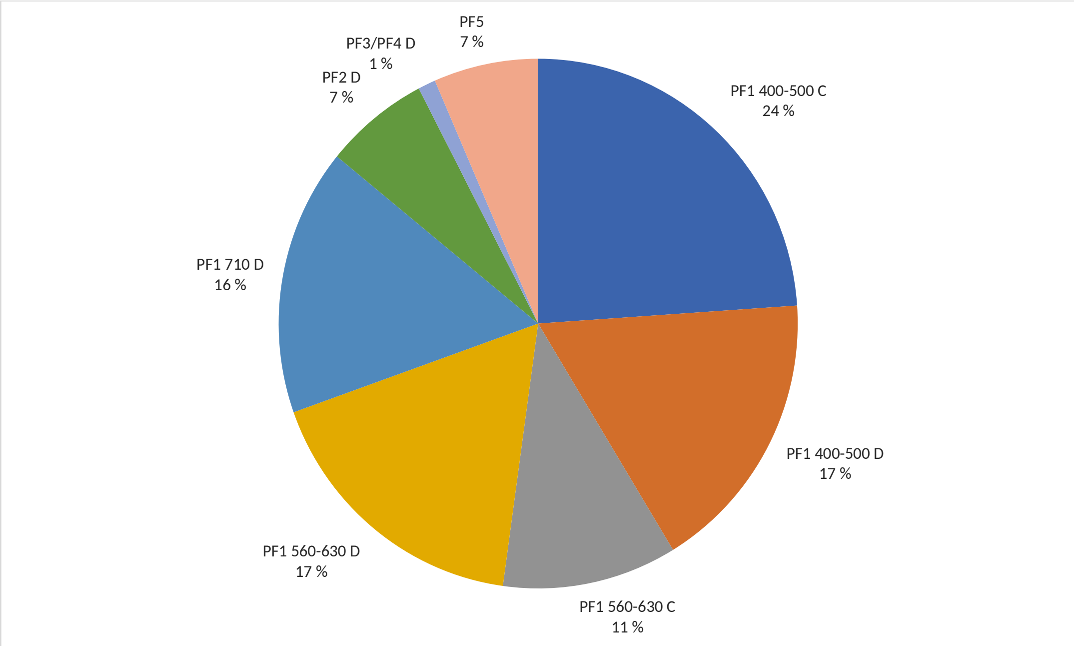

Figure 21. Product group proportions of the potential two-phased ETO model orders (92 motors).

This sample included 1,078 change orders; average was 11.7 changes per motor and the median was 10 (Figure 22). The average number of special components was 13 per motor and the median was 11. The correlation between special components and change orders was 0.76 by examining only the number of special components and change orders. Thus, this indicates that the more there are special components, the more change orders occur.

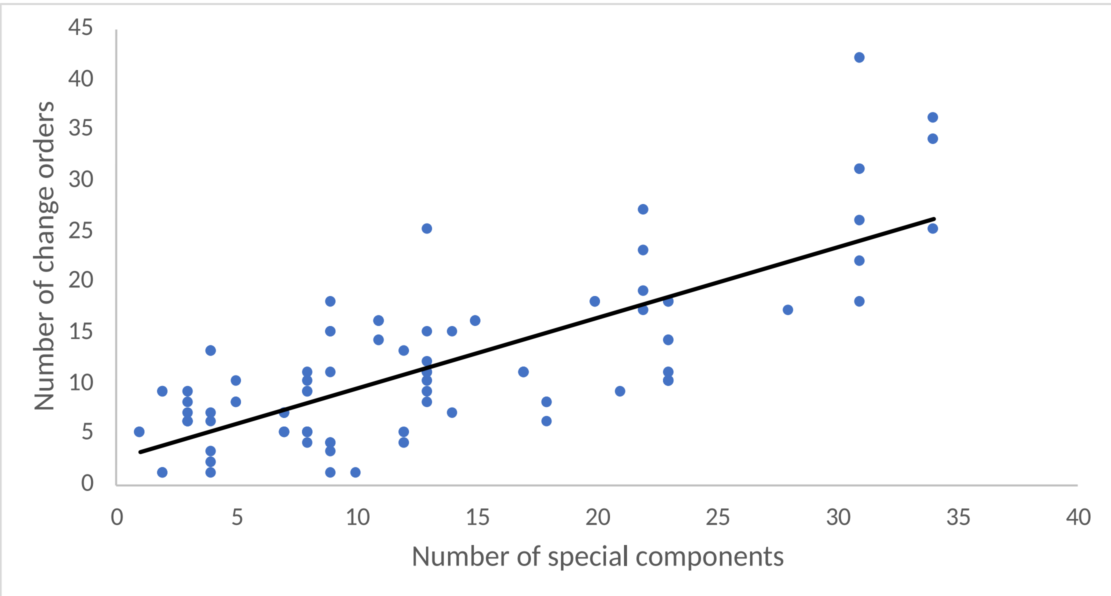

Figure 22. Special components and change orders of the potential two-phased ETO model orders.

After the sample was identified it was possible to examine how these potential two-phased ETO model orders have succeeded. Therefore, lead times from the rotor start date to the packing end date were calculated for all motors (Figure 23). Next, planned rotor start date and packing end date determined the normal lead time. However, some planned lead times were too long because delivery date was postponed during the process, and thus they needed to be corrected according to normal lead time model of the product group. Finally, the difference between planned and actual lead times determined the days that could have been used to invest tied-up capital at 18 % ROE. Most of the purchased materials are arrived in the factory at the beginning of rotor start date and the company does not get its invested money in the motor before it has shipped the motor for the customer. Thus, this time period is valid for the analysis. All these steps were done also for the existing two-phased ETO model orders which delivery date were from January 14th, 2016 to March 23rd, 2018 to identify how the model has worked in the past and also gain insights about the possible mitigation potential per product group.

The highest frequency for lead times above normal was between zero and 35 days. The average lead time from the rotor start date to the packing end date was approximately 72 days, the planned lead time was about 27 days in existing orders (Table 10). In the potential orders the average lead time was 86 days and the average planned lead time was about 33 days. On average, lead time were about 44 days above planned in the existing orders and 53 days above normal in the potential orders. Lead times in PF1 400-500 C product group is 70 % shorter in the existing orders than in the potential orders, and in PF1 560-630 C product group the lead time is 64 %. However, PF1 560-630 D product group lead time is 231 % longer in the existing orders than in the potential orders, in PF2 D 53 % longer and in PF3/PF4 D 68 % longer than in the potential orders. The average lead time in PF1 400-500 D, PF1 710 D and PF5 products groups are long in the potential orders, and thus these can offer a good saving opportunity.

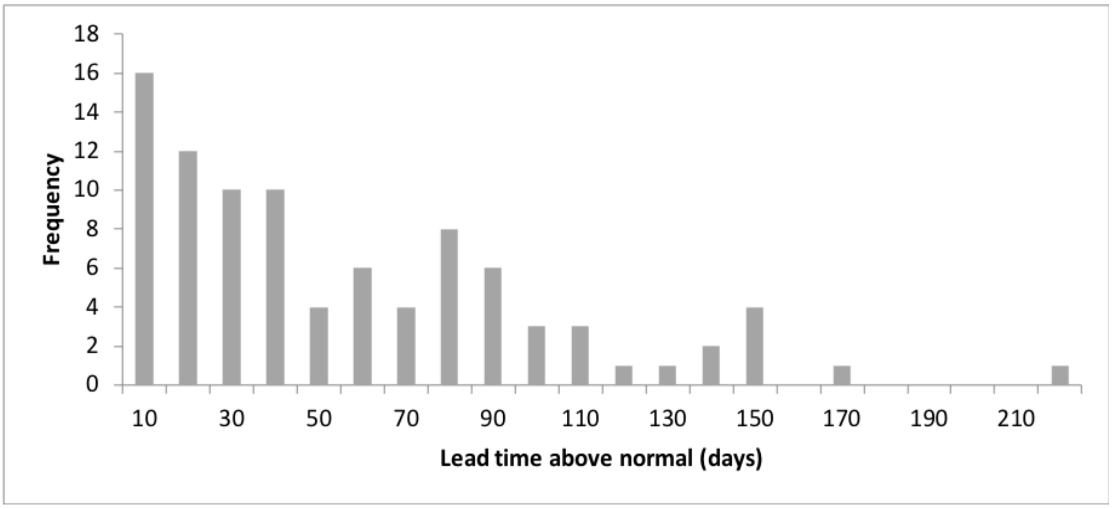

Figure 23. Histogram of lead times above normal.

Table 10. Lead times from the rotor actual start date to packing actual end date of the existing and potential two-phased ETO model orders.

The existing two-phased ETO model orders: lead times above normal								
Product family	PF1 400-500 CLT	PF1 560-630 CLT	PF1 560-630 DLT	PF2 CLT	PF2 DLT	PF3 CLT	PF3 DLT	Total
Sum	236	47	371	50	55	173	1290	2222
Average	15	16	93	10	18	29	99	

Potential two-phased ETO model orders: lead times above normal									
Product family	PF1 400-500 C	PF1 400-500 D	PF1 560-630 C	PF1 560-630 D	PF1 710 D	PF2 D	PF3/ PF4 D	PF5	Total
Sum	1067	1163	433	447	1040	70	59	512	4791
Average	49	73	44	28	72	12	59	85	
Avg. saving potential (%)	70		64	-231		-53	-68		

Finally, both material costs and total actual costs that included material, labour and overhead costs were used to examine the loss of investment opportunity between the existing and potential two-phased ETO model orders.

Loss of investment opportunity based on tied-up capital from the material costs in the existing two-phased ETO model orders is about 104,000 € (Table 11) and about 189,000 € based on total actual costs (Table 12). In the potential order this is about 295,000 € during the period of six months and about 416,000 € based on total actual costs. Moreover, the existing orders did not include PF1 400-500D, PF1 710 D and PF5 and therefore comparison was not possible but the estimations about the loss investment opportunity were possible to be carried out. The average losses of investment opportunity values per one motor of each product were used to compare one motor in each product group because there was a different amount of motors in each product group in the existing and potential orders.

Table 11. Tied-up capital of the existing and potential two-phased ETO model orders based on actual material costs and total actual costs.

The existing two-phased ETO model orders: Loss of investment opportunity based on material costs								
Product family	PF1 400-500 CLT	PF1 560-630 CLT	PF1 560-630 DLT	PF2 CLT	PF2 DLT	PF3 CLT	PF3 DLT	Total
Sum (€)	8,587	1,935	17,294	807	2,743	2,830	70,018	104,214
Average (€)	537	645	4,323	161	914	472	5,386	

Potential two-phased ETO model orders: Loss of investment opportunity based on material costs (EXW last 6 months)									
Product family	PF1 400-500 C	PF1 400-500 D	PF1 560-630 C	PF1 560-630 D	PF1 710 D	PF2 D	PF3/PF4 D	PF5	Total
Sum (€)	31,699	76,927	23,458	41,478	100,293	1,565	907	18,884	295,210
Average (€)	1,440	4,808	2,346	2,592	6,686	261	907	3,147	
Avg. saving potential (%)	63		73	-67		-250	-494		

Table 12. Tied-up capital of the existing and potential two-phased ETO model orders based on total actual costs.

The existing two-phased ETO model orders: Loss of investment opportunity based on total costs								
Product family	PF1 400-500 CLT	PF1 560-630 CLT	PF1 560-630 DLT	PF2 CLT	PF2 DLT	PF3 CLT	PF3 DLT	Total
Sum (€)	12,817	2,763	51,977	1,440	4,883	6,176	108,557	188,613
Average (€)	801	921	12,994	288	1,628	1,029	8,351	

Potential two-phased ETO model orders: Loss of investment opportunity based on total costs (EXW last 6 months)									
Product family	PF1 400-500 C	PF1 400-500 D	PF1 560-630 C	PF1 560-630 D	PF1 710 D	PF2 D	PF3/PF4 D	PF5	Total
Sum (€)	52,154	100,264	32,863	60,069	130,729	2,764	2,194	34,967	416,004
Average (€)	2,370	6,266	3,286	3,754	8,715	460	2,194	5,828	
Avg. saving potential (%)	66		72	-246		-254	-281		

Average loss of investment opportunity based on material costs and total actual costs are largest in PF3 DLT, PF1 560-630 DLT and PF2 DLT in the existing two-phased ETO model orders. The difference between the product groups varies a lot. The highest loss of investment opportunity based on material costs is in the PF3 DLT product group where it was over 5,300 € per motor, and lowest in PF2 CLT product group where it was only 161 €. In addition, the highest loss of investment opportunity based on total actual costs is in PF1 560-630 DLT product group where it was about 13,000, and lowest in the same PF2 CLT product group where it was only 288 €. Therefore, the model has worked in PF2 CLT product group but not in PF1 560-630 DLT and PF3

DLT product groups. Moreover, the labour costs are high in these large PF1s, which increases loss of investment opportunity if lead times are much longer than planned.

In the potential two-phased ETO model orders the loss of investment opportunity based on material costs is largest in PF1 710 D, PF1 400-500D and PF1 560-630 D product groups and the average loss of investment opportunity based on total actual costs is largest in PF1 710 D, PF1 400-500D and PF5 product groups. The average loss of investment opportunity values is generally higher in the potential orders than in the existing orders. The average loss of investment opportunity in all potential orders is 2,773 € as it was in the exiting orders 1,777 €. Therefore, the average saving potential can be approximately 36 % per delivered motor if product groups are neglected. The saving potential in PF1 400-500 C and PF1 560-630 C product groups are especially promising.

The saving potential can be also negative in PF1 560-630 D, PF2 D and PF3/PF4 D product groups. These negative values can be caused by many factors, such as probability for change, internal issues, customers and product specifications. For instance, the sums of loss of investment opportunity in PF2 D and PF3/PF4 D product groups are too small to make right conclusions about the saving potential because probability for the chance is high. The average lead time was over 90 days in PF1 560-630 DLT product group which indicates that there have been large issues during the manufacturing, as well as in PF3 DLT orders that have average lead time of almost 100 days (Table 10). In addition, the model may have been used only for difficult orders in the past without knowing that it does not for instance reduce testing issues if testing requirements are too tight to achieve in the selected product size. Moreover, every order is unique even though the product group is the same.

Due to several challenges to compare the existing orders to the potential orders and gain reliable results in all product groups, the different scenarios were drawn to show financial benefits of the two-phased ETO model in different product groups (Table 13) and the total cumulative savings from January 2018 to December 2020 (Figure 24). The average saving potential value that was 36 %, was assumed to be close to 50 % because all product groups were not possible to be compared. This 50 % saving potential is the moderate scenario, 80 % is the best scenario and 20 % is the worst scenario if the two-phased ETO model is used.

Table 13. Yearly saving potential scenarios from the investment opportunity gained from the material actual costs and total actual costs.

Loss of investment opportunity based on material costs									
Product family	PF1 400-500 C	PF1 400-500 D	PF1 560-630 C	PF1 560-630 D	PF1 710 D	PF2 D	PF3/ PF4 D	PF5	Total
Good scenario: 80%	50,719 €	123,083 €	37,533 €	66,364 €	160,468 €	2,504 €	1,452 €	30,214 €	472,337 €
Moderate scenario: 50%	31,699 €	76,927 €	23,458 €	41,478 €	100,293 €	1,565 €	907 €	18,884 €	295,210 €
Worst scenario: 20%	12,680 €	30,771 €	9,383 €	16,591 €	40,117 €	626 €	363 €	7,553 €	118,084 €

Loss of investment opportunity based on total costs									
Product family	PF1 400-500 C	PF1 400-500 D	PF1 560-630 C	PF1 560-630 D	PF1 710 D	PF2 D	PF3/ PF4 D	PF5	Total
Good scenario: 80%	83,447 €	160,422 €	52,581 €	96,110 €	209,167 €	4,423 €	3,510 €	55,947 €	665,606 €
Moderate scenario: 50%	52,154 €	100,264 €	32,863 €	60,069 €	130,729 €	2,764 €	2,194 €	34,967 €	416,004 €
Worst scenario: 20%	20,862 €	40,106 €	13,145 €	24,027 €	52,292 €	1,106 €	877 €	13,987 €	166,402 €

In the worst scenario, yearly investment opportunity is approximately 118,000 € based on actual material costs and 166,000 € when the total actual costs are taken into account. According to the actual material costs, the cumulative investment opportunity is about 354,000 € with the monthly savings of 9,840 €, and based on total actual costs, the cumulative investment opportunity is approximately 499,000 € with the 13,867 € monthly saving amount.

In the moderate scenario, yearly investment opportunity is approximately 295,000 € based on actual material costs and 416,000 € when the total actual costs are taken into account. According to the actual material costs, the cumulative investment opportunity is about 886,000 € with the monthly savings of 24,601 €. Based on total actual costs, the cumulative investment opportunity is approximately 1.25 million euros with the 34,667 € monthly saving amount.

In the good scenario, yearly investment opportunity is approximately 472,000 € based on actual material costs and 666,000 € when the total actual costs are taken into account. According to the actual material costs, the cumulative investment opportunity is about 1.42 million euros with the monthly savings of 39,361 € and based on total actual costs, the cumulative investment opportunity is approximately 2.00 million euros with the 55,467 € monthly saving amount.

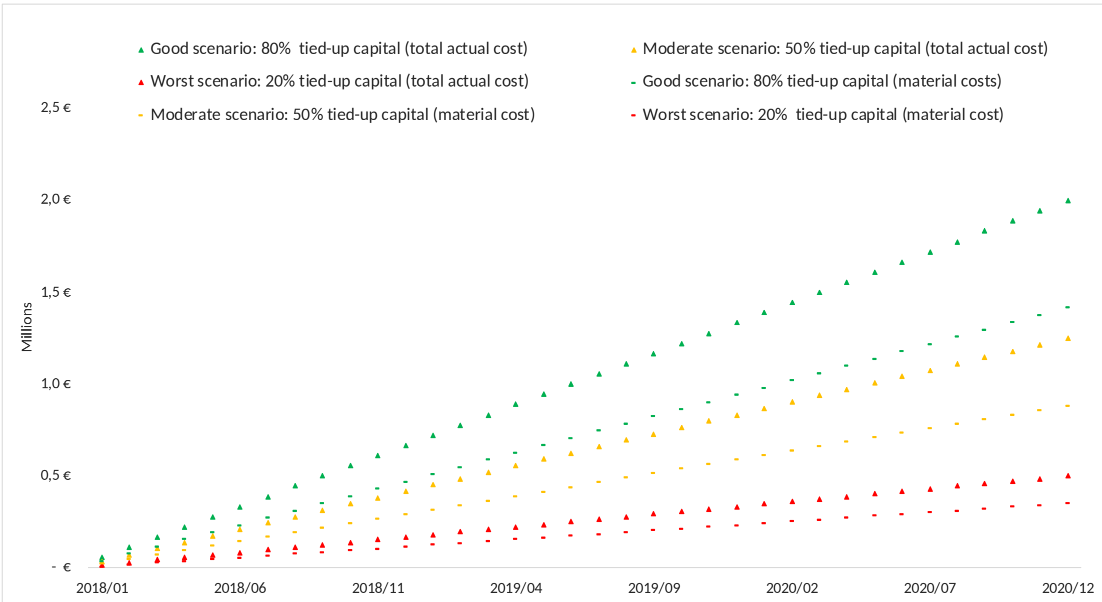

Figure 24. Six scenarios of cumulative savings from January 2018 to December 2020.

4.4.3 Loss of sales and gross profit

The effect of increased lead times to the lost sales and gross profit were calculated by utilizing the calculations of loss of investment opportunity. The difference between planned and actual lead times were summed together and then multiplied by two in order to estimate yearly sum of increased lead times. Next, this yearly sum was divided by two because it was estimated that about half of the increased lead times could have been utilized to get more sales and gross profit. This means that the same motors have used more than one manufacturing slots because of postponements. Another half of the increased lead times were moved to load the existing factory capacity, which reduces the load from earlier weeks. As a consequence, the factory load differs a lot between different weeks after the manufacturing has ended even though the factory load has been stable before the manufacturing slots have been planned. The potential product mix with total lead times from the order-clearing to the packing end date were used to identify the number of new motors that could have been manufactured by using the sum of the wasted days. Finally, average sales price and gross profit per motor were used to estimate the total value of sales and gross profit which were not achieved.

Three different scenarios show the days that are wasted yearly for different product groups (Table 14). The PF1 400-500 C, PF1 400-500 D and PF1 710 product groups offer the highest yearly saving potential. In the good scenario yearly saving potential is 3,833 days that could offer about 1 million additional revenue and 140,000 € more gross profit (Figure 24). Cumulative saving potential is about 417,000 € with the monthly savings of 11,589 €. In the moderate scenario yearly saving potential is 2,396 days that could offer about 633,000 additional revenue and 87,000 € more gross profit (Figure 25). Cumulative saving potential is about 261,000 € with the monthly savings of 7,243 €. The saving potential from the moderate scenario can be closest to the right value because according to analysis, work observations and interviews there are several weeks when the load is moved to another week so that there has not been enough time to sell new orders to the original week. In the worst scenario yearly saving potential is 958 days that could offer about 253,000 € additional revenue and 35,000 € more gross profit (Figure 24). Cumulative saving potential is about 104,000 € with the monthly savings of 2,897 €.

Table 14. Days that are wasted yearly for different product groups.

Days that are wasted yearly for different product groups									
Product family	PF1 400-500 C	PF1 400-500 D	PF1 560-630 C	PF1 560-630 D	PF1 710 D	PF2 D	PF3/ PF4 D	PF5	Total
Good scenario: 80%	1707	1861	693	715	1664	112	94	819	7666
Moderate scenario: 50%	1067	1163	433	447	1040	70	59	512	4791
Worst scenario: 20%	427	465	173	179	416	28	24	205	1916

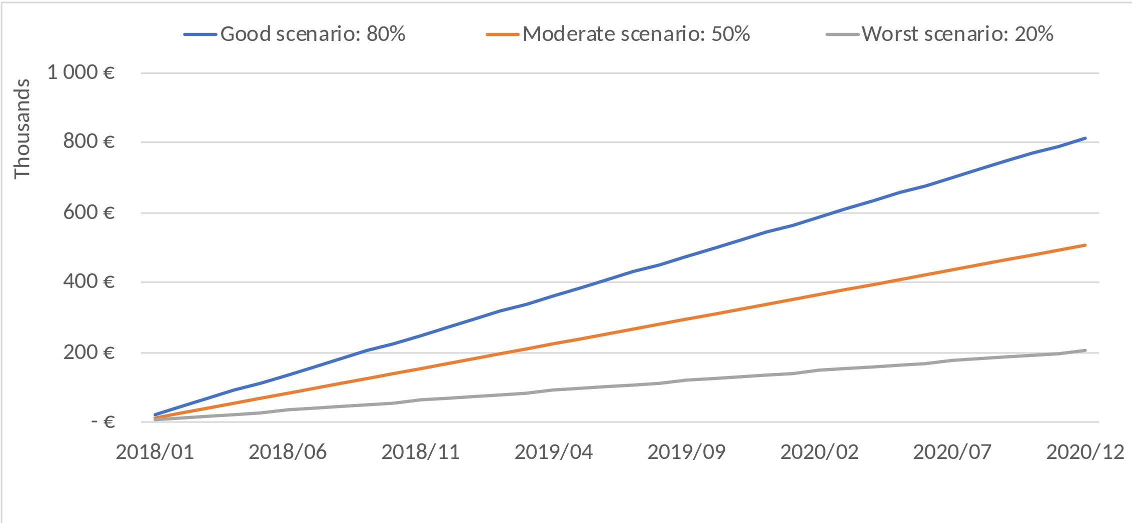

Figure 25. Three scenarios of cumulative savings from January 2018 to December 2020 to increase gross profit.

4.4.4 Total cost of change orders

The total value of negative effects of change orders can be estimated from increased overtime costs, loss of investment opportunity from tied-up capital, and loss of sales and gross profit due to increased lead times. These costs can be combined into two groups in order to show business opportunity in three different scenarios (Figure 26). The first group (tied-up capital + additional GP) includes investment opportunity based on total actual costs and additional gross profit. The good scenario offers a business opportunity of 2.41 million euros with the monthly savings of 67,056 € in the first group. The moderate scenario provides 1.51 million euros with the monthly savings of 41,910 €. Finally, the worst scenario results in 0.60 million euros with the monthly savings of 16,764 €.

The second group (theoretical) includes all previously mentioned costs plus overtime costs. The Good scenario offers 3.01 million euros business opportunity with the monthly savings of 85,522 € in the first group. The moderate scenario offers 1.92 million euros with the monthly savings of 53,451 €. Finally, the worst scenario can achieve 0.77 million euros with the monthly savings of 21,380 €.

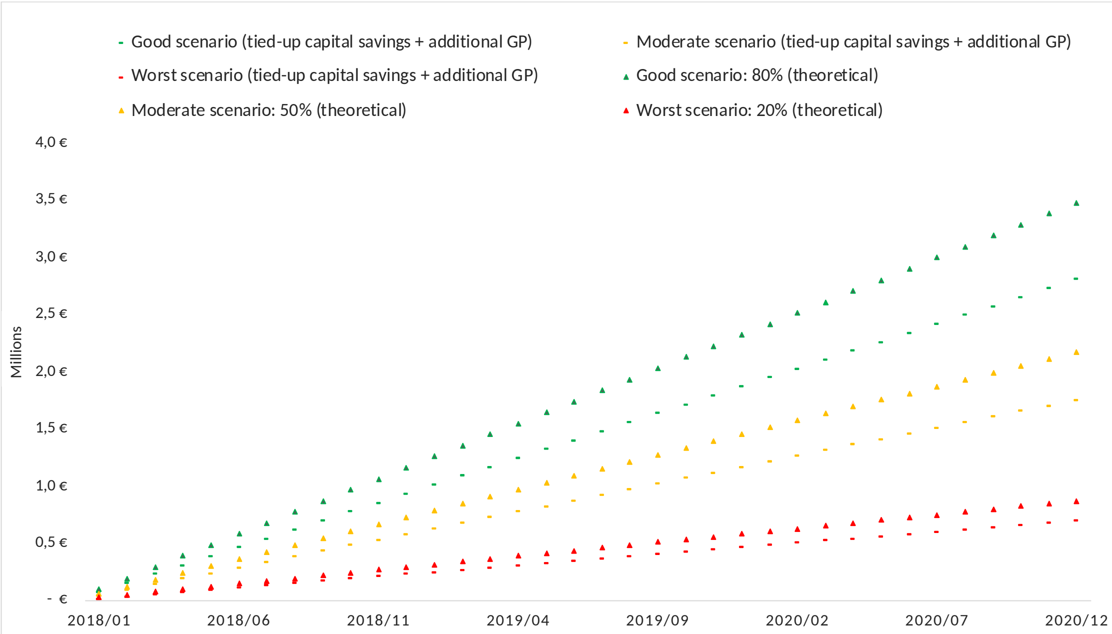

Figure 26. Negative effects of change orders that can be mitigated by using the two-phased ETO model. GP = gross profit.

Table 15 shows how an increase in revenue and utilization rate of the two-phased ETO model affect the theoretical monthly savings. Currently, the utilization rate of the model is at about 10 % of received orders, but if this number can be increased, more savings can be achieved.

Table 15. The effect of revenue and utilization rate of the two-phased ETO model on the theoretical monthly savings in three scenarios (euros).

Good scenario: The effect of revenue and utilization rate of the two-phased ETO model on the theoretical monthly savings

Utilization rate %	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
80 million euros (revenue)	96,545	106,200	116,820	128,502	141,352	155,487	171,036	188,140	206,953	227,649
100 million euros (revenue)	102,579	112,837	124,121	136,533	150,186	165,205	181,726	199,898	219,888	241,877
120 million euros (revenue)	107,708	118,479	130,327	143,360	157,696	173,465	190,812	209,893	230,882	253,971
140 million euros (revenue)	112,196	123,416	135,757	149,333	164,266	180,693	198,762	218,639	240,503	264,553
160 million euros (revenue)	116,203	127,824	140,606	154,666	170,133	187,146	205,861	226,447	249,092	274,001

Moderate scenario: The effect of revenue and utilization rate of the two-phased ETO model on the theoretical monthly savings

Utilization rate %	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
80 million euros (revenue)	60,341	66,375	73,012	80,314	88,345	97,179	106,897	117,587	129,346	142,281
100 million euros (revenue)	64,112	70,523	77,576	85,333	93,867	103,253	113,579	124,936	137,430	151,173
120 million euros (revenue)	67,318	74,050	81,454	89,600	98,560	108,416	119,257	131,183	144,302	158,732
140 million euros (revenue)	70,123	77,135	84,848	93,333	102,667	112,933	124,227	136,649	150,314	165,346
160 million euros (revenue)	72,627	79,890	87,879	96,667	106,333	116,967	128,663	141,530	155,682	171,251

Worst scenario: The effect of revenue and utilization rate of the two-phased ETO model on the theoretical monthly savings

Utilization rate %	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
80 million euros (revenue)	24,136	26,550	29,205	32,125	35,338	38,872	42,759	47,035	51,738	56,912
100 million euros (revenue)	25,645	28,209	31,030	34,133	37,547	41,301	45,431	49,975	54,972	60,469
120 million euros (revenue)	26,927	29,620	32,582	35,840	39,424	43,366	47,703	52,473	57,721	63,493
140 million euros (revenue)	28,049	30,854	33,939	37,333	41,067	45,173	49,691	54,660	60,126	66,138
160 million euros (revenue)	29,051	31,956	35,151	38,667	42,533	46,787	51,465	56,612	62,273	68,500

The main findings for change order occurrence, the negative effects of change orders and mitigation of change orders and their negative effects are summarized in Table 16. The two-phased ETO model reduces the total cost of change orders because more time is used for design and planning of projects and for ensuring the customers' actual needs are identified. As a consequence, a large amount of customer-initiated changes and schedule extensions can be mitigated with the model.

Other strategies that were identified in Chapter 4.2 are needed to mitigate non-value adding activities which change orders can create. Enhancing change order management, increasing transparency between the key stakeholders, and utilizing experience of senior project managers and engineers improve efficiency in the kitting and main assembly stages.

Table 16. Summary of the main findings.

1. Change order (CO) occurrence	2. Negative effects	3. Mitigation
Characteristics of change orders • 2,972 Customer COs • 531 Internal COs • Change orders are mostly related to the structure (34 %) and documentation (29 %) **The main determinants of change order occurrence:** 1.Complex projects (C and D class motors) 2. Inappropriate design and planning of the project 3.Certain customers, industries and countries 4 Other reasons, such as industry specification	**1.Kitting and main assembly issues** • Delays or hold (materials are late) • Decreased labor efficiency (prioritizing, occurred uncertainties • Additional work due to low quality of materials (wrong materials, outdated documents) **1.FAT issues** • 35 % rescheduling rate **3. Value of the negative effects** 1.Overtime costs • From 4,600 € to 18,500€ per month 2. Loss of investment opportunity • From 13,867€ to 55,467 € per month 3. Loss of sales and gross profit • From 2,897€ to 11,589€ per month	**With the two-phased ETO model** 1.Criteria to use the model • Detailed criteria check list is developed 2. Make sure the model works properly internally • Gate process model is developed 3. Ensure the sales force can sell motors by using the model • The sales system need to be updated **→ Mitigates the value of the negative effects** **With other strategies** 1. Enhance change order management 2.Increase transparency and strengthen relationships between all key stakeholders 3.Utilize experience of project managers and engineers 4.Enhance change order and defect reporting to gain more accurate data **→ Mitigates non-value adding activities**

5 Discussion

The main findings and their outcomes are discussed in three sections (Table 16). The first section focuses on change order occurrence which gives a logical foundation for the second section where the negative effects of change orders are discussed. The third section focuses on the mitigation of the negative effects of change orders by using the two-phased ETO model and other strategies. Moreover, possible competitive advantages are discussed. As a consequence, managers and executives receive concrete implications of the phenomenon of change orders in the ETO sector. In addition to these, theoretical contributions for ETO supply chain literature are made and propositions for practical environment are suggested from the viewpoint of change order management.

5.1 Constituents of Change Orders

It was beneficial to examine change order occurrence by focusing on the characteristics of change orders and the reasons for their existence. Without this information, it would not have been possible to identify areas that needed to be observed in more detail, negative effects of change orders and ways to mitigate the negative effects of change orders by using the two-phased ETO model and other strategies.

The case company is severely affected by change orders because yearly it has to process over 3,500 change orders annually to meet the changing customer requirements. This amount of changes accounts for about 2.4 changes per delivered motor which is not a high value on average. However, these changes are not distributed evenly because there are projects with numerous changes while some projects can be carried out without any changes at all (Figure 21). According to the interviews conducted and the data collected at the case company, the change order management is a vital area in which the company needs to succeed because it is part of the customer service and helps achieve better NPS in the industry. Also, Danese et al. (2004) identify change orders as a part of the customer service and a natural phenomenon in the industry.

Due to high amount of different change orders, they are part of order-delivery process at the case company. In addition, the company faces a high pressure to meet customer requests in order to avoid negative publicity and gain high customer satisfaction to secure future sales. Therefore, change orders can be approved even though they cause more costs that can be charged from the customer. This fulfils the criteria of the change order dilemma that was identified in the literature (Uskonen and Tenhiälä, 2012).

The extent of identified constituents that trigger change orders at the case company was expected because products are highly customized, competition is intense and the ETO order-delivery process involves many global stakeholders. For instance, Hsieh et al. (2004) displayed that the scale and the constituents of change orders can be extensive because constituents can be related for instance to underground and safety conditions, natural incidents or work rules/regulations. Both external and internal constituents of change orders were found (research question A1). These changes impact mostly the product planning and design, delivery date and testing program of the project (Figure 8).

The majority of the external changes are customer changes which are, on average, almost six times as common as the internal ones that the case company has to make in order to overcome identified issues or requests (Table 4). These late customer changes, which occur regularly, have been identified to cause a large negative impact on the order-delivery process, as well as late identified errors which are corrected by making internal changes (Gunduz and Hanna, 2005; Jahnukainen et al., 1995).

The planning and design category is the main constituent of change order occurrence at the case company. Out of these changes, many are related to structure and documentation changes that account for more than half of the all change orders (Figure 8). This category, which includes planning and design related problems, is a widely identified cause of change order occurrence (Alnuaimi et al., 2009; Anastasopoulos et al., 2010; Finke, 1998; Hanna et al., 2004; Hsieh et al., 2004). Low quality of orders and internal errors cause design and planning changes at the case company frequently. For instance, the frequency of the documentation errors is high because they occur weekly and can be caused by design errors. Moreover, other frequently occurred issues in the main assembly and kitting stage were outdated documents which can be also related to low quality of orders, design errors or poor change order management.

A long communication chain between a customer and the factory, miscommunication between sales and engineering and rushed orders in the competitive industry are other reasons which can cause late product configuration and specification changes. As a consequence, the aforementioned issues related to the low quality of orders cause numerous change orders at the case company. Low quality of orders is also one of the most common issues identified in the literature (Jahnukainen et al., 1995: Little et al., 2000). For instance, the low quality of orders can be caused by competitive bidding which is sensitive to missing information, miscommunications and errors, and can justify inaccuracies in product configuration and specifications, and triggers changes after the engineering stage (Elfving et al., 2005; Hegde et al., 2005; Little et al., 2000).

Major part of the customer changes can be related to the tendering process if the customers do not know what they want when approving the quotation based on the best estimates of the sales force. Moreover, the interface between customer and sales can trigger changes if customers do not check documents and offers carefully enough.

Scope changes of the customer's project can lead to modifications and schedule changes that account for 11 % of all changes. Change orders between engineering and production stages are common and often cause by issues such as lack of transparency and adequate skills in the interfaces between sales and customer, and sales and engineering, and sometimes by difficulties in understanding and identifying the customer's actual needs. For example, Huffman and Kahn (1998) point out that the manufacturer faces challenges in estimating client's actual needs when the order is placed. In addition to these, there can be many middlemen between the customer and the case company and if there is not enough transparency between sales and engineering, errors are identified too late and need to be fixed during the order-delivery process (Little et al., 2000). One of the root causes of customer changes can be related to the lead times of the product groups at the case company. Due to competitive business, lead times of products are short, and thus there is not enough time for commenting on the documents before the materials are purchased at the case company.

Next, taking a closer look at project-level factors, such product group, difficulty class and the number of components revealed another cause for change order occurrence (Table 2 and Appendix 1). For instance, small and large PF1 product groups with difficulty classes C and D are more sensitive to change orders than PF2/PF3/PF4 product groups because PF1s usually include more special components and are more complex to manufacture. As a general rule, the more special components there are, the more changes are likely to happen. Moreover, component and manufacturing lead times are longer in PF1 product group, which affects the scale of the projects. Anastasopoulos et al. (2010) achieved similar results showing that larger and longer projects trigger more changes than smaller.

There are also other constituents for change orders, such as certain countries, sales regions and customers. For instance, Arab countries and Japan, as well as the sales regions of India, Middle East and Africa (IMEA) and Asia have a relatively large amount of change orders (Figure 15, Tables 4 and 5). Economic sanctions and cultural differences in Arab countries can be one reason for the observed numbers. Furthermore, certain customers request many changes during the process and thus cause many negative effects (Appendix 1). For instance, customers have their own timetables that can require postponing the final acceptance testing date unexpectedly. Most of the changes at the case company were triggered by the customers which is aligned with the similar results achieved by Veldman and Klingenberg (2009). These results are not surprising because cultural differences and the lack of skills between sales support and customer interface, as well as between sales support and project management, can trigger changes if things are understood differently.

The combination of customer specifications and industry classifications together increases complexity of the project and thus triggers to additional changes. Majority of these projects involve the third party in the order-delivery process. For instance, marine components, such as shafts need to be approved by the third party, and certain marine components need to fulfil a NORSOK painting standard. Moreover, API projects can require higher performance requirements from the final acceptance testing stage. If issues occur in these stages, more changes are likely to happen.

Many different vendors and subcontractors around the world are involved in the manufacturing process at the case company because the low-cost vendors are used to increase profits in the competitive industry. Therefore, changes due to suppliers are another reason for the change order occurrence. The low quality of components is another issue, as well as the bottlenecks in the production of subcontractors. These changes can be related to schedule postponements if some component cannot be delivered on time for the use of kitting or production stage (Tables 7, 8 and 9). The aforementioned cases are uncertain issues that can occur at any stage in the order-delivery process and cause change orders. Hicks et al. (2000) highlighted that the ETO supply chains involve many complex supplier relationships, and thus uncertain issues during the process can occur. These constituents show the accrual mechanism of change orders at the case company and show that most change orders are related to the design and planning stage.

5.2 Negative Effects of Change Orders

The negative effects of change orders can be divided into recognized and hidden costs. The recognized costs are mostly related to overmanning because the existing change order management is extensive, frequent and involves many employees to manage occurred change orders daily. Managing change orders at this level has been a concious choice in order to satisfy customers' requests and ensure high customer service level by mitigating the negative effects of change orders. Gunduz and Hanna (2005) highlighted that the change order dilemma causes conscious overmanning costs that decrease the productivity of electrical and mechanical projects. Therefore, the change order management is an inseparable part of the case company's DNA but it is still a remarkable cost category.

Change orders from important customer can be accepted even though it disrupts the process and causes negative effects. Thus, change orders cannot be neglected because negative effects could be higher. This highlights that the change order dilemma is present at the case company and shows that important customers control the order-delivery process. The way of the case company is prioritizing customers is justified because it helps avoid the worst scenarios. Homburg et al. (2008) showed that it is beneficial that companies in B2B and B2C markets prioritize their customers rather than treat them equally because the prioritizing strategy pays off as it enhances customer loyalty and satisfaction.

The extent of the change order management and the number of internal and external stakeholders involved inside and outside of the case company were greater than expected. For instance, daily OTD and change order meetings, as well as weekly regional gate meetings involve numerous participants and interrupt the normal work routines. At the case company, the negative effects are mostly related to cost overruns and schedule delays, which were also identified as negative outcomes by Alnuaimi et al. (2009).

The hidden costs that Miller and Vollman (1985) call non-value adding operations is one of the main research topics of this thesis. Identifying non-value activities in the kitting, main assembly and FAT stages, and estimating the value of hidden overtime costs, lost investment opportunity, and lost sales and gross profit were essential for showing the potential of the two-phased ETO model and other strategies. The work observations in the main assembly and OTD meetings, the interviews in the kitting and main assembly stages, and developing the new criteria for the two-phased ETO model together with the senior project managers and thesis supervisor at the case company enabled to estimate the value of the negative effects that are possible to mitigate. The accurate value of the negative effects was difficult to estimate, and thus worst, moderate and good scenarios were created about the hidden costs that can be mitigated.

Change orders cause more negative effects in the kitting and main assembly stages than in the FAT stage which is not so sensitive to the negative effects of change orders (Tables 7, 8 and 9). The work observations and interviews in the kitting and PF1 main assembly stages revealed several non-value adding activities, such as problem-solving, additional work and inventory, prioritizing and waiting which are caused by change orders. For instance, the project and its manufacturing process can be put on hold after a change order is requested because further instructions are required to continue the work (Hsieh et al., 2004). This research did not focus on labour efficiency but instead showed that change orders and other issues decrease labour efficiency because of frequently occurring delays and prioritization tasks. The existing literature contains similar results that show how delays and work force prioritization can decrease labour productivity by as much as 30 % (Thomas and Napolitan, 1995).

From the managerial perspective, more time, prioritization and additional resources can be required to manage change orders, which can increase delays in the current workflow and risk meeting target timelines. Due to limited labour resources and lack of enough employees who have good problem-solving skills, professionality and adaptability, occurred challenges are difficult to solve out. Furthermore, manufacturing efficiency can decrease because senior employees are prioritized to projects which are either late or have faced change orders, and thus less important projects are postponed. Related to project prioritization, context switching between projects many times during the day requires additional orientation. The negative effects of change orders vary a lot in the PF1 main assembly because anything between one and one hundred hours can be required to overcome the change (Table 9). In the kitting stage, negative effects are not as significant but all identified issues related to changes still decrease the efficiency. The most frequently occurred issues are related to material delays and outdated documents.

The findings of this study show that both kitting and main assembly are sensitive to material delays that can be caused by change orders or supplier issues. Materials are late if suppliers do not have enough time to deliver changed materials. Material delays are some of the main areas that cause non-value adding activities regularly. Waiting in the production or kitting stages can occur. This is costly if the case company aims to reduce production delays but the materials are not available. Therefore, material delays postpone each stage, decrease planned manufacturing time for the next stages, and thus cause bottlenecks in the order-delivery process. Moreover, kitting sets in the warehouse and motors in the main assembly can be put on hold for several days or even weeks, which requires additional warehouse and main assembly space. When the manufacturing slots are used to store motors, there may not be enough place for motors that are put on hold. Changes can make the original documents obsolete and cause confusion in the kitting and main assembly. Hence, there can be many leftover materials in the inventory that are not used for the project, or wrong materials can be used for the project if employees do not notice the changes.

It was beneficial to observe first the main assembly, kitting and FAT stages in order to identify factors that can cause hidden costs and examine how changes affect the order-delivery process efficiency at the later stages. For instance, overtime hours and prioritizing may be needed to manage late changes and project schedule extensions to meet FAT deadlines and avoid OTD failures and penalties. These results highlight the impact of late occurred change orders. If change orders had been managed at the beginning of the order-delivery process, less non-value adding activities in the kitting and main assembly stages would have been occurred. As was identified in the literature (Gunduz and Hanna, 2005; Jahnukainen et al., 1995), change orders that have occurred later have a larger impact than changes that have occurred early.

Overtime costs is the first type of hidden costs that is identified in this thesis (research question A2). However, the effect of change orders on overtime hours has not been measured accurately because overtime costs can be also caused by other reasons, such as lack of employees, unstable work load, material delays, quality issues and human errors which need to be fixed with overtime works. Nevertheless, work observations and interviews indicate that the significant amount of overtime costs can result from change orders. Therefore, high amount of overtime hours is also used at the case company to reduce the negative effects of change orders. Overtime hours were also identified in literature as a way to overcome the negative effects of change orders (Hanna et al., 2004).

The second type of hidden costs is loss of investment opportunity (research question A2). These hidden costs are related to schedule extensions. Schedule extensions are common at the case company but these postponements, which can be caused by material delays or issues related to documents, increase lead times, and can cause loss of investment opportunity, sales and gross profit. Schedule extensions can be caused by many issues, such as a slow change order management process (Williams et al., 2003). Therefore, schedule delays occur in the order-delivery process, which can postpone planned delivery dates. As a consequence, more tied-up capital is held in the inventory.

The comparison between the existing two-phased ETO model orders and potential two-phased ETO model orders did not give robust information about the exact value that can be saved but some results were promising (Tables 11 and 12). For instance, lead times were, on average, 40 % shorter in the existing orders than in the potential orders (Table 10). Moreover, these results can be caused by many factors; for example the model has not been used properly, there has been internal or external issues or the projects have been complex to implement.

Finding the potential ETO model orders was vital to explore hidden costs related to the loss of investment opportunity, sales and gross profit which are realistic to be mitigated by using the model and other strategies. Many of the potential two-phased ETO projects take more time than planned from rotor start date to packing end date, which causes loss of investment opportunity. There are major differences between projects and product groups with different difficulties. If lead times are longer in the normal ETO approach than in the two-phased ETO model, loss of investment opportunity is higher. To calculate the loss of investment opportunity, a ROE of 18 % was used to estimate the tied-up capital based on material and total costs. The loss of investment opportunity that can be mitigated by using the two-phased ETO model and other strategies were 55,467 € in the good scenario per month, 34,667 € in the moderate scenario and 13,867 € in the worst scenario. These account for 665,606 €, 414,004 € and 166,402 € per year, respectively, depending on the scenario. The results of loss of investment opportunity based on total actual costs are realistic because most of the potential orders were PF1 products which are more valuable and expensive to manufacture than other products.

Last type of hidden costs is lost sales and gross profit (research question A2). If a delivery date is postponed or an order is cancelled after booking, the order reserves manufacturing slots. If there is not enough time to get a new order after the order has been cancelled or the delivery date is postponed, the company's revenue can decrease, and it has more capacity relative to the workload if all the capacity is not used to reduce delays. These are hidden costs that are difficult to charge from the customer in order to avoid negative NPS. A sample of the two-phased ETO model orders was used to estimate lost sales and gross profits and to test the new criteria for the model. The results show the negative effects of change orders on lead times. For instance, the schedule for the factory load can be significantly different afterwards when the factory load is affected by postponements. Cumulative saving potential is in the good scenario 417,000 € per year if 7666 days can be utilized for the new orders, in the moderate scenario 261,000 € if 4791 days can be utilized for the new orders and in the worst scenario 104,000 € if 1916 days can be utilized for the new orders. Based on analyses and work observations, the value of lost sales and gross profit is realistic and a vital hidden cost area that should be mitigated.

Three theoretical business opportunity scenarios were used to conclude all negative effects that can be mitigated by using the two-phased ETO model (research question A2). The total value of the negative effects can reach 1.3 % of the monthly revenue of the case company. In the good scenario 85,522 € can be mitigated per month, in the in the moderate scenario 53,451 € and in the worst scenario 21,380 €. If the two-phased ETO model is used correctly, the cumulative savings from January 2018 to December 2020 amount to 3.01 million euros in the good scenario, 1.9 million euros in the moderate scenario and 0.77 in the worst scenario. Riley et al. (2005) identified that change order costs can be between 5 % and 15 % of value of the project and Hsieh et al. (2004) discovered that costs can be from 10 % to 17 %. When all possible hidden and identified costs are considered, this cost range can be actually much higher in worst projects that are facing a large amount of changes that postpone delivery date many times, reserve manufacturing slots several times and in which mitigation strategies are absent. For instance, lead time was over one hundred days above the normal in many projects (Figure 22 and Appendix 1). In addition, the high level of competition at the case company's industry can force it to price it products lower at the cost of its gross profit. This leads to the first proposition.

Proposition 1. Change order costs can account for over 17 % of value of the most complex projects in the competitive ETO sector.

5.3 Mitigation of Change Orders with Two-phased ETO Model

Due to numerous constituents of change orders that are embedded in the processes of the case company, change orders are part of the ETO process now and also in the future. The two-phased ETO model does not the solve all issues that were identified but if it is used correctly, it will help mitigate the negative effects of the most challenging projects that cause most of the changes and negative effects (Figure 15). Moreover, the suggested steps in Figure 14 are required in order to ensure the model is implemented correctly because its implementation failed in the past (research question B1). Preventing all change orders is difficult because change orders can be caused by many unforeseeable factors, such as customer behaviour and the manufacturer itself (Uskonen and Tenhiälä, 2012).

First, the two-phased ETO model ensures that enough time is allocated for the design and planning of a project, and customers understand the scope of the project and have enough time to comment on the documents and design of the project. Serag et al. (2010) identify similar results showing that it is beneficial to allocate enough time for the design and planning stage. The two-phased ETO model ensures that no materials are purchased before the manufacturing release. Even though the two-phased ETO model increases work at the beginning of the order-delivery chain, it is necessary for decreasing the amount of the costlier order changes at the end of order-delivery process. Hanna et al. (2004) state that additions, design changes and errors can in theory be mitigated during the design stage, and for this purpose the new two-phased ETO model was developed.

Second, the two-phased ETO increases the possibility of identifying customers’ actual needs before the manufacturing process begins. Identifying customers' actual needs at the beginning of the order-delivery process is challenging but when that happens, the quality of design and manufacturing can be improved (Huffman and Kahn, 1998; Rahman and Shariff, 2003). The results show that the existing two-phased ETO model orders are less affected, which reduces costs and the negative effects. For instance, lead times from rotor start date to planned packing end date were shorter than similar orders that were not manufactured by using the two-phased ETO model. The two-phased ETO model can reduce the negative effects from projects that are most sensitive to changes and cause most of the hidden costs. This ensures the product configurations are more robust after the manufacturing has begun. Thus, the company can be sure the scope of the project is accepted by the customer and avoid disputes between the customer. Since more time is used to check the preliminary configuration and specification of the product, it is possible to ensure more robust product configuration, avoid ambiguities, and reduce change orders and their negative effects (Little et al., 2000; Serag et al. 2010; Zwick and Miller, 2004).

Third, the two-phased ETO model helps mitigate schedule extensions because it ensures that the manufacturing process will be affected less by late changes. For instance, it is possible to double check design and possible issues that may occur before the manufacturing release has given, which brings down the production lead time. Thus, the actual delivery times can be shorter, which decreases inventory carrying costs and work-in-process inventories (Easton and Moodie, 1999). Lead time is critical for each product type, and it can produce the winning quotation. It is speculated that lead times can increase in the two-phased ETO model because the model adds additional pre-CODP phase into the ETO supply chain by giving a customer more time to comment on and accept the designs before placing an order. Thus, this theoretically increases lead times compared to normal lead-time models. However, if order changes occur after the order is placed, lead times can actually be much longer than with the normal models. Moreover, preparing for changes after receiving an order can increase the actual lead times because additional buffer is used for issues that can be caused by change orders. As a result, a shorter delivery time reduces time to make new changes (Partanen and Haapasalo, 2004) when the case company postpones the OPP point to as late as possible. This leads to the second proposition.

Proposition 2. Production lead times can be shorter in ETO projects if more time is used for checking all critical product designs before procurement and production.

Finally, the two-phased ETO model increases transparency between customer and the case company if a common platform is used for information sharing and target development. Because lead times are longer in the challenging projects that, at the same time, are most potential two-phased ETO model projects, there is more time for cooperating with the customer and doing all critical changes before the actual product design is frozen. For instance, the case company could provide real-time information about the project schedule and tentative deadlines for the customers. Hoover et al. (2001) recommend using a platform for information sharing and target development in order to increase cooperation with the customer and improve customer value and satisfaction.

Once the needs of these customers have been identified and enough time is used for the design and planning stage, the lead time of the project is closer to the planned lead time model. The case company can achieve better investment opportunity, more revenue and gross profit, reduce overtime costs, and avoid on-time delivery risks. Hence, there is a better chance to avoid negative effects that account for a large proportion of the value of the project. The benefits of identifying customers actual need right at the beginning are proved in the literature, Günhan et al., (2007) observed that the negative effects of change orders do not exceed more than 5 % of the total value of the project if the project scope is highlighted early enough, and the engineering and project experience of the engineering and project reviews are utilized.

5.4 Mitigation of Change Orders with Other Strategies

Many of the change orders cannot be prevented and their negative effects cannot be mitigated with the two-phased ETO model if the changes have occurred after the manufacturing release. The current practices, such as daily OTD meetings and ad hoc meetings for critical change orders, are effective to overcome some of the negative effects of change orders. For instance, all projects which are late and are likely to cause OTD failures are managed on a daily basis as well as all new change orders.

However, other ways, such as such as more efficient overtime work planning, more accurate charging for change orders, improving the current change order management process and gaining more appropriate change order data help in overcoming the negative effects of change orders (research question B2). For instance, overtime hours should be done during the weekdays instead of expensive weekend hours if there is enough manufacturing time in complex projects. Moreover, it is essential to identify all associated costs, such as overhead, purchasing services and additional office and engineering activities when preparing a cost estimate for the change order request in order to charge enough from the customer (Hsieh et al. 2004). In particular, agility is needed when the change order has already occurred. At the case company, these other mitigation strategies need to be focused on improving the agility to overcome the negative effects of change orders. This finding is supported by Gosling and Naim (2009) who state that an ETO customer-driven supply chain needs agility.

Most of the essential strategies to mitigate the negative effects of change orders which were identified in Chapter 4.2 can be divided into five areas. First, transparency between the case company, customer, sales and suppliers could be improved in order to ensure better agility when responding to change orders (research question B2). In the current state it is possible that some vital information does not always reach the kitting and main assembly (Tables 8 and 9). More effort should be put on the interface between sales and customer by focusing on certain sales offices and customers in order to decrease the amount of change orders and to create more transparency. Increasing transparency and cooperation with the customer is one way. For instance, customer could see a timeline of the project with predetermined deadlines and could monitor the manufacturing of the motor in-real time. Information goes in both directions in real-time in one platform that allows simulating the project schedule in case the customer wants to make changes to it. Using this kind of approach, it could be possible to identify the most typical changes, material lead times and change prices for the customer at each stage of the project. As a result, document errors and subcontractor issues can be reduced, and procurement efficiency can be improved. The effective sharing of knowledge and information has also been identified in the existing literature as a way for gaining competitive advantage (Hicks et al., 2000, Olhager, 2003).

Second, the results (Tables 8 and 9) indicate that change order information does not always reach the critical shareholders, which means that the quality of change order management should be improved (research question B2). For instance, leftover materials can be stored in the warehouse for several years and their potential is not leveraged even though they can be suitable for other projects. Furthermore, the efficiency of change order management can be improved, as well as the consistency of the change process in order to avoid internal mistakes. For instance, project manager may approve the change order for the customer without changing the EXW date and discussing with the procurement department and production planning about issues that may arise. Moreover, time zone differences between Asia and Finland can increase response times, as well as cultural differences. Thus, it is vital to increase transparency between sales offices where the response times is long. As a result, sharing information early enough to right stakeholders and taking all possible risks into account, the quality of change order management can be significantly improved, and a more agile and efficient manufacturing process can be attained and secure efficient manufacturing process. For instance, the faster the response times to change orders are, the less costs occur (Hanna et al., 2004). Moreover, accurate documentation of change orders and daily operations helps manage the occurred changes and defend possible claims (Serag et al., 2010).

Third, due to high degree of customization, the experience of senior engineers, senior production employees and project managers should be leveraged more efficiently to increase agility and reduce hidden costs of change orders (research question B2). For instance, a strong relationship between engineering and production can be built to transfer knowledge between these departments, which helps in identifying more mitigation practices at the design and planning stage. In addition, recognizing product groups and difficulty classes with special components and customer specifications helps reduce the negative effects. If the experience of the project managers and engineers is utilized, the negative effects can be reduced more effectively (Gunduz and Hanna, 2005).

Fourth, quality of data and its utilization could be improved (research question B2). For instance, the notifications from the processes should be improved because there may not always be an appropriate defect category to put an issue in. The only option is to report the issue forward using the "other" category if there is no exact match of the defect. This “other” category does not give enough information for data analyses in the case company. Therefore, a significant part of notifications should be addressed in an improved way to gain more informative data about the negative effects of change orders. Now major issues caused by change orders can be caught only by the work observation and interviews but if had there been a more accurate reporting system, there could have been more vital information related to change orders available. For example, it could be beneficial to get more information about changes and the workload that changes cause in the production.

Finally, the current way is to manufacture motors at the same place in the assembly slot but this is not efficient if late change orders force a project to be put on hold. Therefore, it could be possible to mitigate these changes by changing this assembly slot philosophy to assembly line philosophy where motors are manufactured in different assembly lines, similar to a car factory (research question B2). Pilot projects have already been launched to study whether it is possible to manufacture the motors with low degree of difficult by using this strategy. However, this requires further research that should be focused on components and different main assembly sub-stages. Hence, long-term monitoring and numerous pilot projects are required to change the manufacturing philosophy due to the high degree of customization. In the future there could be fast, moderate and slow manufacturing lines for the different degrees of difficulty of products.

5.5 From Change Order Dilemma to Competitive Advantage

If the two-phased ETO model is used correctly and for the right product types, it can create significant benefits for both the case company and the customer. As described earlier in this thesis, the model mitigates the negative effects of change orders which, in a highly competitive industry leads to competitive advantages for the case company.

First, from the company's point of view, less tied-up capital is needed in the two-phased ETO model because materials can be purchased after the customer has accepted the design, and further changes to required materials are less likely to happen. This was shown in the financial analysis of this thesis.

Second, higher profit margins can be achieved when some hidden costs, such as schedule extensions, can be eliminated. This means that less motors need to be stopped during the manufacturing, and thus manufacturing flow and labor efficiency remain stable at a high level. Therefore, non-value adding activities can be reduced from the order-delivery process, which decreases schedule extensions and helps increase the inventory turnover ratio. As a result, inventory costs and work in process inventories can be reduced as also shown by Easton and Moodie (1999). If the company can also increase the rate of on-time deliveries, it can positively affect labor efficiency as employees' motivation increases if fewer orders are rushed ready under high pressure.

Third, more sales can be achieved due to shortened delivery times if there are less changes and EXW postponements during the process. This increases gross profits for the case company and can enable a more profitable growth strategy that is also one of the case company's main goals. In addition, if the original master production schedule does not change during the process, factory workload remains more stable, and there is more workforce available at any given time.

From the customer's point of view, the model can improve both the customer experience and the quality of the final product. Due to the improved cost structure, the company can offer lower prices for the customer while capturing the same profit levels as earlier. For some customers, a shorter delivery time is more important, and the model is beneficial also in this case as it shortens the delivery time and makes it more predictable. As a result, the company can keep the promised delivery date more often and gain a higher customer satisfaction and net promoter score (NPS).

Second, the two-phased ETO model strengthens the transparency between the customer and the factory. For the customer, transparency means that the customer can see the project milestones in real-time, understand when changes can still be made to the project and, evaluate what the impact of these changes is. For the company, transparency means it can understand the real needs of the customer more easily and avoid costs that could be incurred due to unforeseen changes.

All potential of the two-phased ordering model and other strategies are difficult to estimate. One reason is that the reduced workload can also transfer employees' workload to more profitable tasks if there are less changes and their impacts are smaller. Also, the hours used to fulfill change orders are not measured on their own, and thus there is no exact number for them at the case company. Anyway, the two-phased ETO model creates benefits that can be used for marketing advantage (Easton and Moodie,

1999) and for creating competitive advantages through improved quality and customer experience (Olhager, 2003).

5.6 Limitations and Future Research

This research has several limitations. First, the sample of 92 motors from the observation period of six months can have certain biases. Sample selection can have an impact on the results (Miles and Huberman, 1994). External validity can be limited because the findings are based on the results of a single case study, relatively small sample size and a short research period. Self-reported data can also contain several potential sources of bias. External view from outside of the case company could have revealed new outcomes but due to complexity of the topic, the experience and awareness of daily challenges related to change orders at the case company were necessary to gain a holistic view from the change order phenomenon.

Second, the developed criteria for the two-phased ETO model can change in the future because the numerous constituents of change orders can evolve over time. Therefore, the criteria need to be monitored and updated to correctly identify the right projects that should be manufactured by using the two-phased ETO model. The benefits that the model and other strategies are estimations based on analyses, interviews and validations conducted during the research. One of the critical decisions was to use the ROE of 18% to examine the loss of investment opportunity. Based on the economic conditions and investment decisions at the case company in the future, the ROE can be different in practice, which changes the results for the loss of investment opportunity.

Third, prior research on change orders in the ETO sector is limited. For this reason, there was no concrete starting point for studying the negative effects and other issues in the context of ETO sector, similar products and comparable lead times. Due to the differences between products and factories, it is difficult to say how the mitigation strategies that were identified in this study would work in other factories at the case company or in other companies. Different operation systems can also affect the results as they have differences in how numbers are reported and how data has been processed after inputting it in the system.

Fourth, the limited scope of this thesis and lack of reporting at the case company created further limitations. Due to limited resources, it was not possible to implement the two-phased ETO model for full use because it could have required expanding the research scope. The quality of available data related to identified issues in the order-delivery process was limited because many issues in the main assembly can be reported as other defects, which does not fully specify the details of the issue. In addition, according to work observations and interviews, many factors that could have been beneficial for the study are not reported at all at the case company.

Building on these limitations, there are several areas for future research. Internal factors, such as electrical design and components, could reveal a more accurate accrual mechanism for change orders. In addition, modularization and standardization options for the highly customized class A products could be studied in detail because modularization and standardization were identified as effective practices for mitigating change orders in the literature (Hoover et al., 2001). This would involve studying what is the optimal level of modularization and standardization so that the products can still be manufactured to satisfy the customers' varying needs.

Another large area for further research is to observe external factors related to the customers. In long and complex sales channels, it is the factory-sales-customer interfaces that cause many of the problems associated with change order management and information flows. Thus, it would be beneficial to study the implementation of the two-phased ETO model on a global scale where sales channels span across multiple countries and stakeholders. Studying ways for improving information flows between these interfaces helps improve transparency and reduce misunderstandings which cause change orders. This research area could help identify constituents of changes that were not found in this thesis.

Next, it could be studied how the two-phased ETO model can improve sales and marketing. As discussed in Chapter 5.5, the model can improve customer experience and delivery times that can be used in marketing to boost sales. One specific topic is to study how customers react if they do not know the exact delivery time but only get a preliminary delivery date. Also, research is needed to determine what the consequences for the customer should be if they request late changes but have not selected the two-phased ETO model even though it would have been available. With the existing models the customers may have had more freedom to request late changes that the case company has not charged enough for. If these late changes are fully charged from the customer, the impact on customer satisfaction needs to be clarified.

Also, it is critical to observe how sales quotation tool can sell orders if there is not exact delivery date. For instance, sales could use two prices for the motor, cheaper for the two-phased ETO orders and a bit expensive for normal ETO orders. In addition, if the model is used, it is vital to research how the real-time information is shared with the customer in order to secure high transparency between the customer and the case company. The more there are studies related to customers' behavior and attitudes for the model, the more valuable insights can be achieved. Moreover, change order management, business development and marketing practices can be enhanced.

Despite the limitations mentioned here, the research in this thesis successfully identified the main reasons for change order occurrence and their impact on the order-delivery chain at the case company. However, the implementation of the two-phased ETO model on a global scale requires a significant amount of further research, especially on external factors affecting the model and the critical interfaces between different stakeholders. When it comes to the limitations of the case study methodology, a quantitative research in a multi-case study environment is required to generalize the results to larger population, that is, all projects and companies in the ETO industry.

6 Conclusions

Existing literature identifies change order dilemma as a major challenge in the highly competitive ETO manufacturing sector. Managing and accepting change orders decreases efficiency in ETO supply chains and introduces additional costs, but refusing to accept changes from customers has a negative impact on customer experience and future sales. This thesis contributes to the ETO literature by focusing on a less-studied area of change order management, that is, the low-volume industrial sector. An in-depth single case study method is used to analyse the change order dilemma and give concrete recommendations for the case company.

The research is divided into two main topics. First, in the context of the case company, change orders and their negative effects are examined. The analysis shows that change order occurrence is common in complex product groups and can be caused by both internal and external factors. At the case company, external factors, which include customer-initiated changes, are more common than internal factors, such as design errors and inadequate order management practices. Furthermore, a scenario analysis is used to estimate the total value of the negative effects that change orders cause. On average, this can amount to more than one percent of the annual revenue of the case company. This figure is a combination of visible costs, such as overmanning and overtime hours, and hidden costs, such as lost investment opportunity and disturbances in the process flow.

Second, this thesis investigates ways of mitigating the negative effects. As the main component of the research, a two-phased ETO model is developed together with improved criteria for selecting appropriate projects for the model. The conclusion is that the two-phased ETO model helps mitigate the negative effects of the most challenging projects predictively because more time is allocated for project design and planning. This means there are less changes after the manufacturing phase has started, which results in lower costs and improved efficiency of the order-delivery process. In addition to the ETO model, improved change order management, transparency between key stakeholders and leveraging experience of senior employees are suggested as effective strategies for mitigating the negative effects of change orders.

Ideally, the two-phased ETO model and other strategies should be implemented simultaneously. This enhances the performance of the order-delivery chain, helps overcome the change order dilemma and can ultimately create competitive advantages for the case company in the forms of improved customer experience and better cost structure. Future research on this topic should focus on the implementation details of the two-phased ETO model on a global scale in order to identify the key stakeholders and issues in the critical interfaces between factories, sales and customers.

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Appendices

Appendix 1. The Potential Two-phased ETO Model Orders

Sales order	Product group	SCs	COs	Paint	Industry	Country	TestType	Cust Test	Shared Test	Special Tests	Rating agency	LT	N LT	LT abobe N.
P9210HG300	PF2 D	1	5	C5	IND.12-Oil and Gas I	IT	RO	No	No	Yes	No	34	27	7
P9210HG300	PF2 D	1	5	C5	IND.12-Oil and Gas I	IT	RO	No	No	Yes	No	36	27	9
P9083HG200	PF1 400-500 C	2	1	C3	Water and Waste water	EG	TY	Yes	Yes	No	No	56	28	28
P9083HG200	PF1 400-500 C	2	1	C3	Water and Waste water	EG	TY	Yes	Yes	No	No	58	28	30
P8798HG300	PF2 D	2	9	C5M	Oil and Gas	AT	RO	Yes	No	No	No	31	26	5
P8798HG300	PF2 D	2	9	C5M	Oil and Gas	AT	RO	Yes	No	No	No	37	26	11
P8934HG201	PF1 400-500 C	3	8	C5M	Marine	NO	CT	Yes	Yes	No	Yes	16	16	0
P8934HG202	PF1 400-500 C	3	6	C5M	Marine	NO	CT	Yes	Yes	No	Yes	20	20	0
P8934HG203	PF1 400-500 C	3	6	C5M	Marine	NO	CT	Yes	Yes	No	Yes	15	15	0
P8934HG204	PF1 400-500 C	3	7	C5M	Marine	NO	CT	Yes	Yes	No	Yes	44	28	16
P8934HG205	PF1 400-500 C	3	6	C5M	Marine	NO	CT	Yes	Yes	No	Yes	49	28	21
P8934HG206	PF1 400-500 C	3	9	C5M	Marine	NO	CT	Yes	No	No	Yes	15	15	0
P9184HG200	PF1 400-500 C	4	3	C3	DONT USE XY-Usage Un	AE	TY	No	No	No	Yes	32	32	0
P8820HG200	PF1 400-500 C	4	2	C3	Other Industries	ES	RO	Yes	Yes	Yes	No	35	24	11
P8820HG202	PF1 560-630 C	4	1	C3	Other Industries	ES	RO	Yes	Yes	Yes	No	33	25	8
P8973HG200	PF1 560-630 C	4	13	C3	IND.12-Oil and Gas I	TH	TY	Yes	No	No	No	84	30	54
P8973HG200	PF1 560-630 C	4	13	C3	IND.12-Oil and Gas I	TH	TY	Yes	No	No	No	100	30	70
P8975HG200	PF1 560-630 C	4	6	C3	Power Generation	BE	RO	No	No	Yes	No	41	30	11
P9058HG200	PF1 560-630 C	4	7	C3	IND.12-Oil and Gas I	ID	TY	Yes	No	No	No	154	30	124
P8754HG200	PF1 560-630 D	5	8	C5I	IND.12-Oil and Gas I	MY	TY	No	Yes	Yes	No	27	24	3
P8754HG200	PF1 560-630 D	5	8	C5I	IND.12-Oil and Gas I	MY	TY	No	Yes	Yes	No	28	24	4
P8930HG300	PF3/PF4 D	5	10	C3	Other Industries	US	TY	No	No	Yes	No	81	22	59
P8956HG200	PF1 560-630 D	7	7	C5I	IND.12-Oil and Gas I	NL	TY	Yes	No	Yes	No	40	28	12
P9080HG200	PF1 710 D	7	7	C3	IND.16-Other Industr	US	TY	Yes	Yes	Yes	No	99	46	53
P9080HG201	PF1 710 D	7	5	C3	IND.16-Other Industr	US	RO	No	No	Yes	No	87	46	41
P9080HG202	PF1 560-630 D	7	5	C3	IND.16-Other Industr	US	TY	Yes	Yes	Yes	No	51	34	17
P9080HG202	PF1 560-630 D	7	5	C3	IND.16-Other Industr	US	TY	Yes	Yes	Yes	No	51	34	17
P8558HG202	PF1 400-500 C	8	9	C3	TRA.1-Marine	FI	TY	Yes	Yes	Yes	Yes	128	25	103

Sales order	Product group	SCs	COs	Paint	Industry	Country	TestType	Cust Test	Shared Test	Special Tests	Rating agency	LT	N LT	LT abobe N.
P8672HG200	PF1 710 D	8	10	C5I	Oil and Gas	US	RO	No	No	Yes	No	185	46	139
P8672HG201	PF1 710 D	8	5	C5I	Oil and Gas	US	RO	No	No	Yes	No	116	27	89
P8672HG201	PF1 710 D	8	5	C5I	Oil and Gas	US	RO	No	No	Yes	No	114	46	68
P8672HG202	PF1 710 D	8	5	C5I	IND.12-Oil and Gas I	US	RO	No	No	Yes	No	126	46	80
P8672HG202	PF1 710 D	8	5	C5I	IND.12-Oil and Gas I	US	RO	No	No	Yes	No	135	46	89
P8672HG203	PF1 710 D	8	4	C5I	Oil and Gas	US	RO	No	No	Yes	No	158	63	95
P8768HG200	PF1 560-630 D	8	9	C3	Oil and Gas	ID	RO	Yes	No	No	No	59	27	32
P8558HG201	PF1 400-500 C	8	11	C3	TRA.1-Marine	FI	TY	Yes	Yes	Yes	Yes	128	25	103
P8069HG201	PF1 560-630 D	9	3	C3	Marine	FI	RO	No	No	Yes	Yes	49	33	16
P8069HG202	PF1 560-630 D	9	4	C3	Marine	FI	TY	No	Yes	Yes	Yes	44	30	14
P8069HG203	PF1 560-630 D	9	4	C3	Marine	FI	TY	No	No	Yes	Yes	49	30	19
P8781HG200	PF1 400-500 D	9	11	C5M	Oil and Gas	DE	RO	Yes	No	Yes	No	34	22	12
P8908HG200	PF1 400-500 C	9	1	C3	Other Industries	TW	TY	Yes	No	Yes	No	36	30	6
P8216HG200	PF1 400-500 C	9	18	C5M	DONT USE XY-Usage Un	QA	TY	Yes	No	Yes	No	183	35	148
P8216HG201	PF1 400-500 C	9	15	C5M	DONT USE XY-Usage Un	QA	TY	Yes	No	Yes	No	183	35	148
P8216HG202	PF1 400-500 C	9	15	C5M	DONT USE XY-Usage Un	QA	TY	Yes	No	Yes	No	183	35	148
P8700HG212	PF1 560-630 D	10	1	C3	UT.4-Water and Waste	CH	TY	Yes	No	Yes	No	48	24	24
P8873HG300	PF2 D	11	14	C5M	Other Industries	IT	TY	Yes	No	Yes	No	59	27	32
P8846HG200	PF1 560-630 D	11	16	C5I	Oil and Gas	KR	TY	Yes	Yes	No	No	64	36	28
P8846HG201	PF1 560-630 D	11	16	C5I	Oil and Gas	KR	TY	Yes	Yes	No	No	64	36	28
P8055HG201	PF1 560-630 C	12	13	C3	Marine	FI	TY	Yes	Yes	Yes	Yes	63	27	36
P8055HG202	PF1 560-630 C	12	4	C3	Marine	FI	RO	No	No	Yes	Yes	63	27	36
P8055HG203	PF1 560-630 C	12	5	C3	Marine	FI	RO	No	No	Yes	Yes	64	27	37
P8998HG204	PF1 400-500 C	13	9	C3	Marine	TW	TY	No	No	No	Yes	64	23	41
P8997HG204	PF1 400-500 C	13	11	C3	Marine	TW	TY	No	No	No	Yes	71	27	44
P8431HG302	PF5	13	25	C3	Pulp and Paper	US	RO	No	No	Yes	No	113	46	67
P8431HG303	PF5	13	12	C3	Pulp and Paper	US	RO	No	No	Yes	No	112	46	66
P8431HG304	PF5	13	15	C3	Pulp and Paper	US	RO	No	No	Yes	No	104	46	58
P8431HG305	PF5	13	11	C3	Pulp and Paper	US	RO	No	No	Yes	No	140	46	94
P8431HG306	PF5	13	10	C3	Pulp and Paper	US	RO	No	No	Yes	No	190	46	144
P8431HG307	PF5	13	8	C3	Pulp and Paper	US	RO	No	No	Yes	No	129	46	83

Sales order	Product group	SCs	COs	Paint	Industry	Country	TestType	Cust Test	Shared Test	Special Tests	Rating agency	LT	N LT	LT abobe N.
P8803HG200	PF1 400-500 D	14	7	C5I	IND.12-Oil and Gas I	GB		No	No	Yes	No	82	30	52
P8877HG200	PF1 400-500 D	14	15	C5I	Oil and Gas	DE	TY	Yes	Yes	Yes	No	99	41	58
P8584HG200	PF1 560-630 C	15	16	C5M	Oil and Gas	JP	TY	Yes	No	Yes	No	56	28	28
P8584HG200	PF1 560-630 C	15	16	C5M	Oil and Gas	JP	TY	Yes	No	Yes	No	57	28	29
P9059HG200	PF1 400-500 C	17	11	C5M	Oil and Gas	GB	TY	Yes	No	Yes	No	64	33	31
P9059HG200	PF1 400-500 C	17	11	C5M	Oil and Gas	GB	TY	Yes	No	Yes	No	64	33	31
P8769HG202	PF1 560-630 D	18	6	C5M Norsok	Oil and Gas	NO	TY	Yes	Yes	No	No	52	47	5
P8671HG200	PF1 400-500 D	18	8	C5M	Oil and Gas	US	TY	Yes	No	Yes	No	58	28	30
P8769HG201	PF1 560-630 D	18	8	C5M Norsok	Oil and Gas	NO	TY	Yes	Yes	No	No	66	45	21
P9070HG200	PF1 400-500 C	20	18	C5M	IND.12-Oil and Gas I	GB	TY	Yes	Yes	Yes	No	113	35	78
P9070HG200	PF1 400-500 C	20	18	C5M	IND.12-Oil and Gas I	GB	TY	Yes	Yes	Yes	No	115	35	80
P8421HG301	PF2 D	21	9	C5I	Oil and Gas	JP	TY	Yes	Yes	Yes	No	29	23	6
P8971HG200	PF1 400-500 D	22	23	C5I	IND.12-Oil and Gas I	DE	TY	Yes	No	Yes	No	112	35	77
P8702HG200	PF1 710 D	22	27	C5M	Oil and Gas	GB	TY	Yes	Yes	Yes	No	72	37	35
P8702HG201	PF1 710 D	22	19	C5M	Oil and Gas	GB	RO	No	No	Yes	No	112	41	71
P8702HG202	PF1 710 D	22	17	C5M	Oil and Gas	GB	RO	No	No	Yes	No	90	42	48
P8959HG200	PF1 560-630 D	23	11	C5I	IND.12-Oil and Gas I	US	RO	Yes	No	Yes	No	171	37	134
P8808HG200	PF1 400-500 D	23	14	C3	UT.1-Electric Utilit	SE	TY	Yes	Yes	Yes	No	107	27	80
P8808HG201	PF1 400-500 D	23	10	C3	UT.1-Electric Utilit	SE	TY	Yes	Yes	Yes	No	111	25	86
P8808HG202	PF1 400-500 D	23	10	C3	UT.1-Electric Utilit	SE	TY	Yes	Yes	Yes	No	112	22	90
P8808HG203	PF1 400-500 D	23	10	C3	UT.1-Electric Utilit	SE	TY	Yes	Yes	Yes	No	103	22	81
P8963HG200	PF1 710 D	23	18	C5	IND.12-Oil and Gas I	GB	TY	Yes	Yes	Yes	No	71	58	13
P8963HG200	PF1 710 D	23	18	C5	IND.12-Oil and Gas I	GB	TY	Yes	Yes	Yes	No	79	42	37
P8828HG200	PF1 400-500 D	28	17	C3	Oil and Gas	JP	TY	Yes	No	Yes	No	37	30	7
P8750HG201	PF1 400-500 D	31	22	C5	IND.12-Oil and Gas I	JP	TY	Yes	No	Yes	No	72	35	37
P8421HG200	PF1 400-500 D	31	26	C5I	Oil and Gas	JP	TY	Yes	Yes	Yes	No	138	37	101
P8389HG200	PF1 400-500 D	31	31	C5M Norsok	IND.12-Oil and Gas I	GB	TY	Yes	Yes	Yes	No	113	41	72
P8389HG200	PF1 400-500 D	31	31	C5M Norsok	IND.12-Oil and Gas I	GB	TY	Yes	Yes	Yes	No	255	41	214
P8421HG201	PF1 400-500 D	31	18	C5I	Oil and Gas	JP	TY	Yes	Yes	Yes	No	26	24	2
P8462HG200	PF1 710 D	31	42	C5I	Oil and Gas	JP	TY	Yes	No	Yes	No	145	46	99
P8597HG202	PF1 560-630 D	34	25	C5I	IND.12-Oil and Gas I	JP	TY	Yes	No	Yes	No	148	75	73
P8597HG200	PF1 710 D	34	34	C5I	IND.12-Oil and Gas I	JP	TY	Yes	No	Yes	No	160	46	114
P8597HG201	PF1 400-500 D	34	36	C5I	IND.12-Oil and Gas I	JP	TY	Yes	No	Yes	No	199	35	164

Appendix 2. The Existing Two-phased ETO Model Orders

Sales order	Product group	SCs	Paint	Industry	Country	Test Type	Cust Test	Shared Test	Special Tests	Rating agency	N LT	LT	LT above N
P7171HG300	PF2 CLT	x	C3	XY.1-END USAGE UNKNO	BH	RO	No	No	No	No	21	35	14
P7171HG200	PF1 560-630 CLT	x	C3	XY.1-END USAGE UNKNO	BH	RO	No	No	No	No	24	34	10
P7171HG200	PF1 560-630 CLT	x	C3	XY.1-END USAGE UNKNO	BH	RO	No	No	No	No	24	33	9
P7053HG303	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	126	103
P7053HG303	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	126	103
P7053HG303	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	126	103
P7053HG303	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	126	103
P7053HG300	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	24	122	98
P7053HG300	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	24	122	98
P7053HG300	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	24	122	98
P7053HG302	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	122	99
P7053HG302	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	122	99
P7053HG302	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	121	98
P7053HG302	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	23	121	98
P7053HG301	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	25	120	95
P7053HG301	PF3 DLT	x	C3	IND.12-OIL AND GAS I	IN	TY	Yes	No	Yes	No	25	120	95
P7250HG200	PF1 560-630 CLT	x	C3	IND.7-METALS	IN		No	No	No	No	22	50	28
P6959HG201	PF1 400-500 CLT	x	C3	XY.1-END USAGE UNKNO	PL	TY	Yes	No	No	Yes	22	41	19
P6959HG202	PF1 400-500 CLT	x	C3	XY.1-END USAGE UNKNO	PL	RO	Yes	No	No	Yes	22	39	17
P6959HG200	PF1 400-500 CLT	x	C3	XY.1-END USAGE UNKNO	PL	RO	Yes	No	No	Yes	22	39	17
P7916HG300	PF2 CLT	x	C3	IND.12-OIL AND GAS I	QA	RO	Yes	No	Yes	No	17	23	6
P7916HG300	PF2 CLT	x	C3	IND.12-OIL AND GAS I	QA	RO	Yes	No	Yes	No	17	23	6
P7894HG203	PF1 400-500 CLT	x	C3	UT.1.6-POWER GENERAT	BE		No	No	No	No	22	37	15
P7894HG203	PF1 400-500 CLT	x	C3	UT.1.6-POWER GENERAT	BE		No	No	No	No	22	37	15
P8054HG200	PF1 400-500 CLT	23	C5I	IND.12-OIL AND GAS I	CH		No	No	No	No	22	42	20
P7894HG202	PF1 400-500 CLT	x	C3	UT.1.6-POWER GENERAT	BE		No	No	No	No	21	35	14
P7894HG202	PF1 400-500 CLT	x	C3	UT.1.6-POWER GENERAT	BE		No	No	No	No	21	35	14
P7894HG202	PF1 400-500 CLT	x	C3	UT.1.6-POWER GENERAT	BE		No	No	No	No	21	35	14
P8219HG200	PF1 400-500 CLT	6	C3	UT.4-WATER AND WASTE	QA		No	No	No	No	20	46	26
P8221HG301	PF3 CLT	4	C3	UT.1-ELECTRIC UTILIT	DE	TY	No	Yes	Yes	No	16	22	6
P8221HG301	PF3 CLT	4	C3	UT.1-ELECTRIC UTILIT	DE	TY	No	Yes	Yes	No	16	22	6
P8221HG301	PF3 CLT	4	C3	UT.1-ELECTRIC UTILIT	DE	TY	No	Yes	Yes	No	16	52	36
P8221HG301	PF3 CLT	4	C3	UT.1-ELECTRIC UTILIT	DE	TY	No	Yes	Yes	No	16	21	5
P8219HG201	PF1 400-500 CLT	6	C3	UT.4-WATER AND WASTE	QA		No	No	No	No	20	38	18
P8219HG201	PF1 400-500 CLT	6	C3	UT.4-WATER AND WASTE	QA		No	No	No	No	20	38	18
P8219HG201	PF1 400-500 CLT	6	C3	UT.4-WATER AND WASTE	QA		No	No	No	No	20	38	18
P8219HG202	PF1 400-500 CLT	6	C3	UT.4-WATER AND WASTE	QA		No	No	No	No	21	30	9
P8539HG300	PF2 CLT	3	C3	IND.12-OIL AND GAS I	IQ	RO	No	No	No	No	18	30	12
P8539HG300	PF2 CLT	3	C3	IND.12-OIL AND GAS I	IQ	RO	No	No	No	No	18	30	12
P7811HG300	PF2 DLT	x	C3	IND.12-OIL AND GAS I	BE	TY	Yes	No	Yes	No	22	40	18
P7811HG300	PF2 DLT	x	C3	IND.12-OIL AND GAS I	BE	TY	Yes	No	Yes	No	22	40	18
P7811HG300	PF2 DLT	x	C3	IND.12-OIL AND GAS I	BE	TY	Yes	No	Yes	No	26	45	19
P8397HG200	PF1 560-630 DLT	32	C5M	IND.12-OIL AND GAS I	US	TY	Yes	No	Yes	No	83	190	107
P8483HG300	PF3 CLT	8	C3	IND.12-OIL AND GAS I	IR	TY	Yes	Yes	Yes	No	16	74	58
P8483HG300	PF3 CLT	8	C3	IND.12-OIL AND GAS I	IR	TY	Yes	Yes	Yes	No	16	78	62
P7594HG200	PF1 560-630 DLT	x	C5I	IND.12-OIL AND GAS I	US	TY	Yes	No	Yes	No	104	190	86
P7594HG201	PF1 560-630 DLT	x	C5I	IND.12-OIL AND GAS I	US	TY	Yes	No	Yes	No	96	189	93
P7594HG202	PF1 560-630 DLT	x	C5I	IND.12-OIL AND GAS I	US	TY	Yes	No	Yes	No	104	189	85
P9161HG200	PF1 400-500 CLT	5	C5M	IND.12-OIL AND GAS I	US	TY	Yes	Yes	Yes	Yes	27	28	1
P9161HG200	PF1 400-500 CLT	5	C5M	IND.12-OIL AND GAS I	US	TY	Yes	Yes	Yes	Yes	27	28	1

Appendix 3. Email Questions

1. Which are the most significant challenges/issues in the small and large PF1 product group main assembly?
2. What can these challenges/issues cause, how frequently do they occur and how can they be mitigated?
3. How do internal and customer changes related to schedule, document, structure and testing affect the small and large PF1 main assembly?
4. What additional actions are required to implement these changes?

Appendix 4. Interview Questions for the Final Acceptance Testing

1. Which are the most significant challenges/issues in FAT stage?
    - How do the challenges/issues impact the FAT and following stages?
    - Which product families are the most sensitive for issues?
    - What are the possible root causes in the background?
    - How frequently does the challenge/issue occur?
    - What ways are there to mitigate the challenge/issue and possible impact?

2. How can change orders affect FAT stage?
    - How can change orders impact the FAT and following stages?
    - Which product families are the most sensitive for the change?
    - What are the possible root causes in the background?
    - How frequently does the change occur?
    - What ways are there to mitigate the change and possible impact?

Appendix 5. Interview Questions for Sub-assemblers (setting)

1. Which are the most significant challenges/issues in the small and large PF1 product group subassembly (setting stage)?
2. What can these challenges/issues cause, how frequently do they occur and how can they be mitigated?
3. How do internal and customer changes related to schedule, document, structure and testing affect the small and large PF1 subassembly (setting stage)?
4. What additional actions are required to implement these changes?
5. What ways are there to mitigate the issues?

Appendix 6. Work Observation Table

Work stage	Start time	Finishing time	Possible issues and their impact	Training of new employees Yes/No	Finished before evening work shift?
Stator connection					
Stator inserting					
Auxiliary box installation connections and					
Main termnnal box assembly					
Rotor inserting					
Bearings					
Equipment					
Installation of heat exchaning equipment					

Appendix 7. Interview Questions

Interview questions for the Project Managers, Head of Project Management, Team Leader of Project Management and Team Leader of Production Planning

1. Do you have any new constituents of change order occurrence that should be noticed?

2. Do you have any suggestions to improve the new criteria of using the two-phased ETO model?